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APEX
527

DATA BOOK

Physical Properties and Flow Characteristics of Air

J. L. Hobbs
M. E. Lapides

GENERAL ELECTRIC
AIRCRAFT NUCLEAR PROPULSION DEPARTMENT

Index

(1) Aerodynamics
(2) Air Properties and Flow Characteristics

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DATA BOOK
Physical Properties and Flow Characteristics of Air

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Thermodynamics and Mechanics Development Sub-Section

M. E. Lapides
Technical Design Sub-Section

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GENERAL ELECTRIC
AIRCRAFT NUCLEAR PROPULSION DEPARTMENT
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Abstract

This report presents data on the physical properties and flow characteristics of air. These data have been compiled from several different sources outside the Department and from charts prepared within the Department. The report was prepared as a data book to be used as an aid in calculations.

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Air Enthalpy Tables

Use of Relative Pressure Charts on Enthalpy Tables

The derivation and use of the temperature-enthalpy - relative-pressure relationship are outlined in Keenan and Kaye.* The use of the enthalpy chart and the derivations will not receive attention. However, the use of the relative-pressure - temperature chart will be reproduced in part.

The purpose of the relative pressure - temperature chart is to facilitate the finding of temperature and enthalpy of isentropic compression or expansion processes. The solution involves use of the ratio

$$\left(\frac{P_a}{P_b}\right) = \frac{P_{ra}}{P_{rb}}$$

where (P_a/P_b) is compressor pressure ratio, and P_r is the relative pressure.

The following example illustrates the use of the chart shown in Table 1.

From the chart, for $T_1 = 520^{o}R$ the values $P_r = 2.505$ and $h_1 = 28.76$ Btu/lb are obtained, where the subscript 1 refers to compressor inlet conditions. If a compressor pressure ratio of 6 to 1 is assumed, then to obtain compressor outlet conditions for isentropic compression, outlet relative pressure is found by using the ratio given above.

$$P_{r2} = \left(\frac{6}{1}\right) \text{ x } 2.505 = 15.03$$

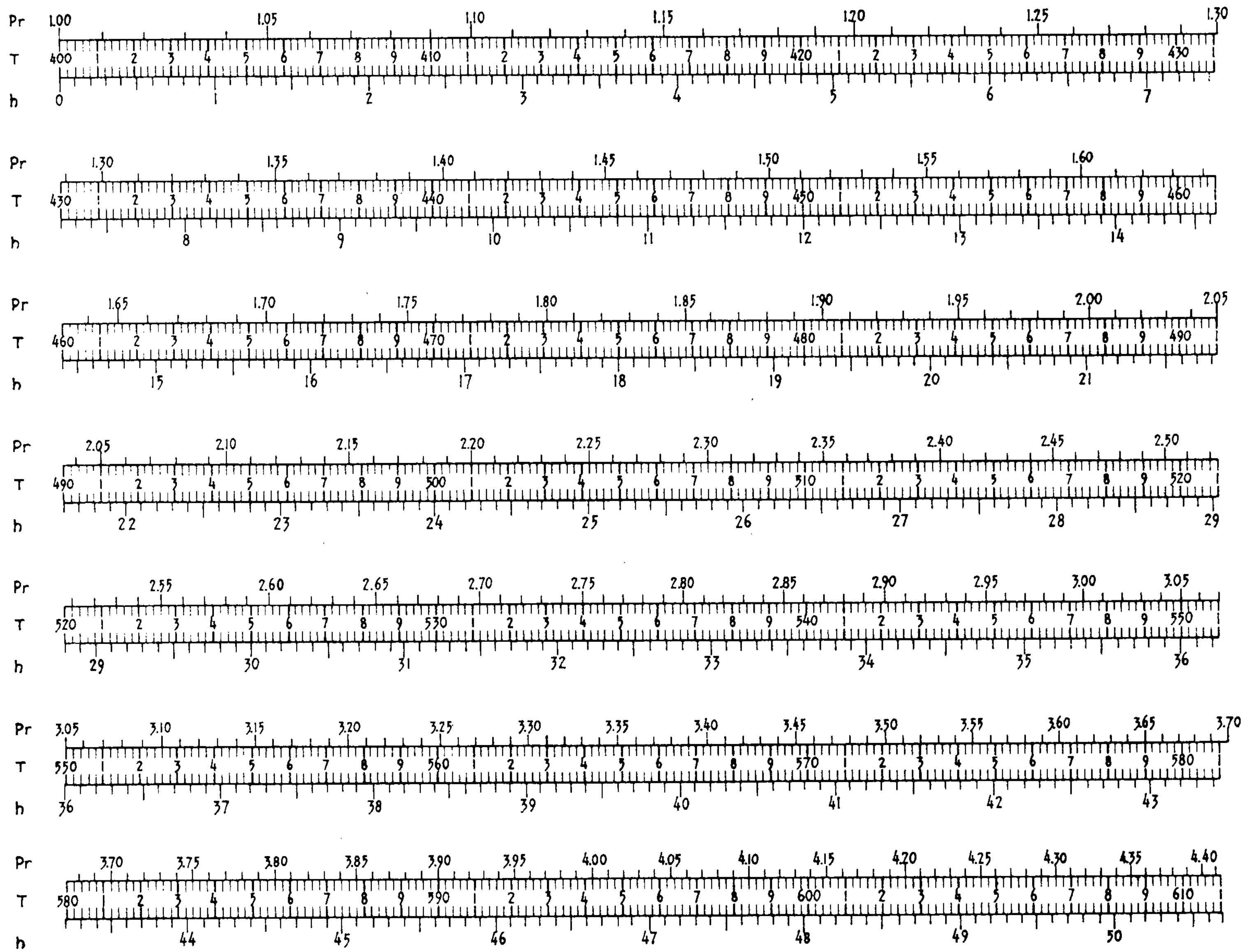
Enthalpy and temperature at the compressor outlet for isentropic compression may be read at this value (15.03) on the chart.

$$h_{2S} = 112.1 \text{ Btu/lb}, \quad T_{2S} = 864.3^{o}R$$

*J. H. Keenan and J. Kaye, *Thermodynamic Properties of Air*, 1945.

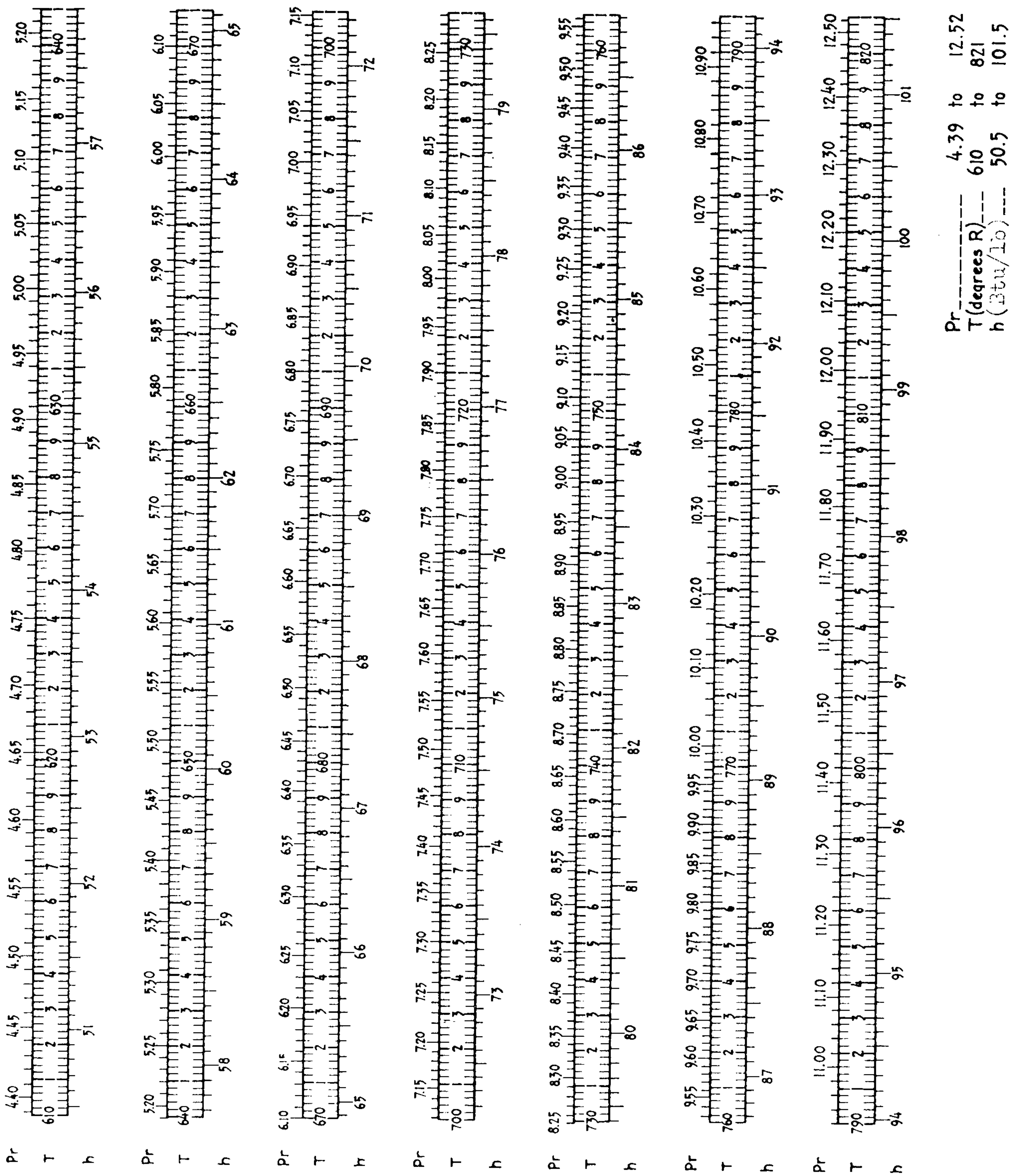
TABLE 1

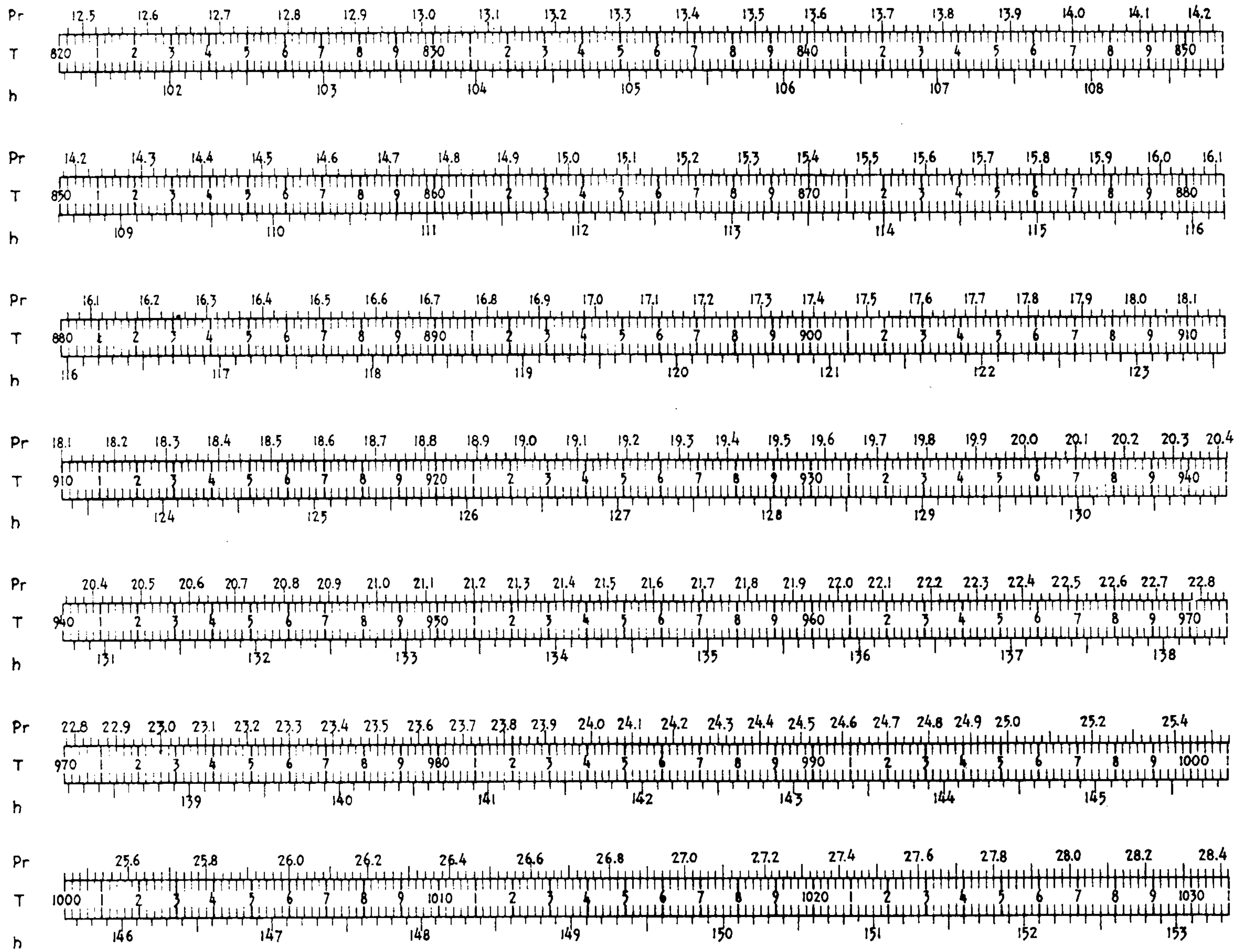
AIR ENTHALPY TABLES



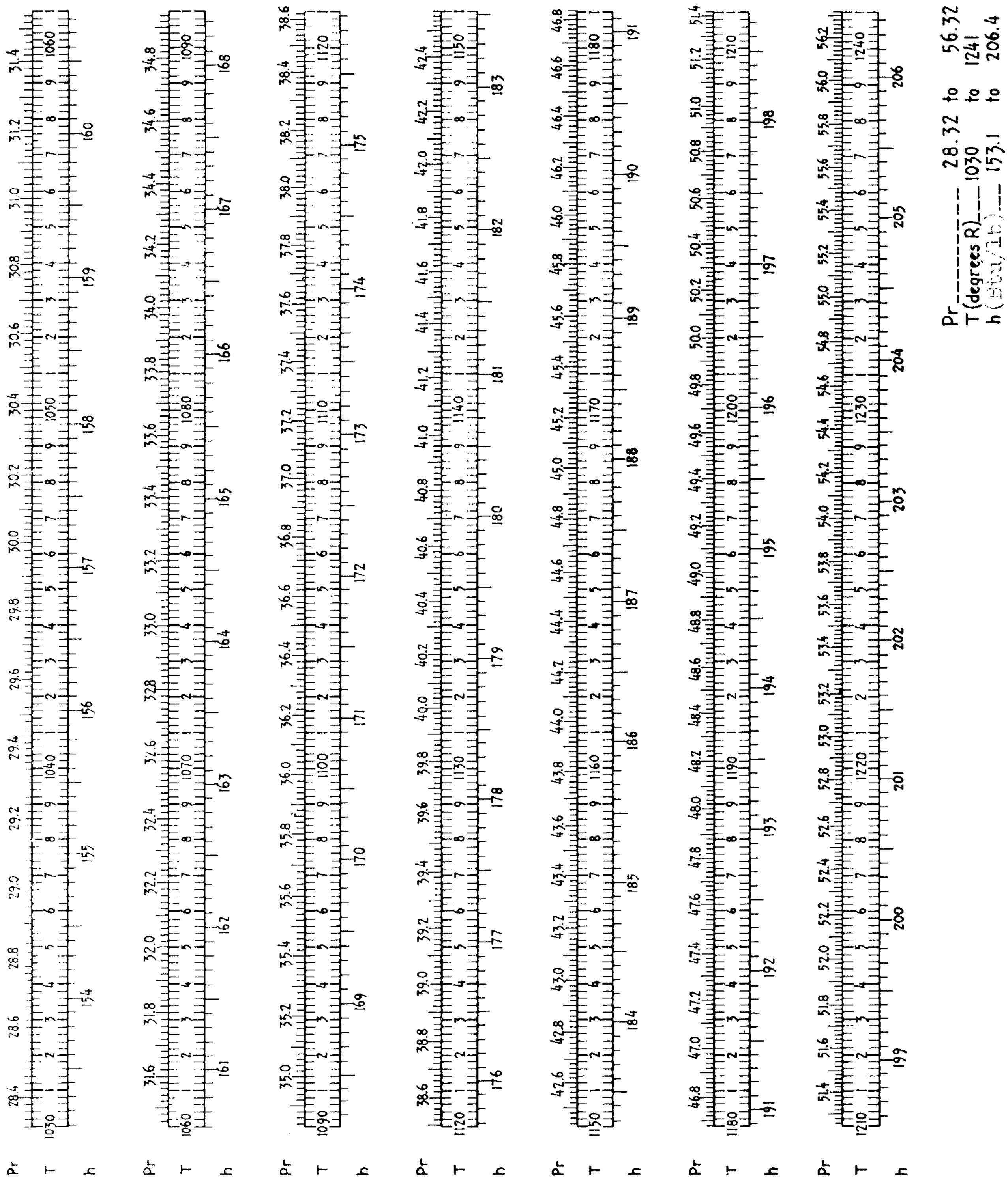
(Source: Naval Bureau of Ships)

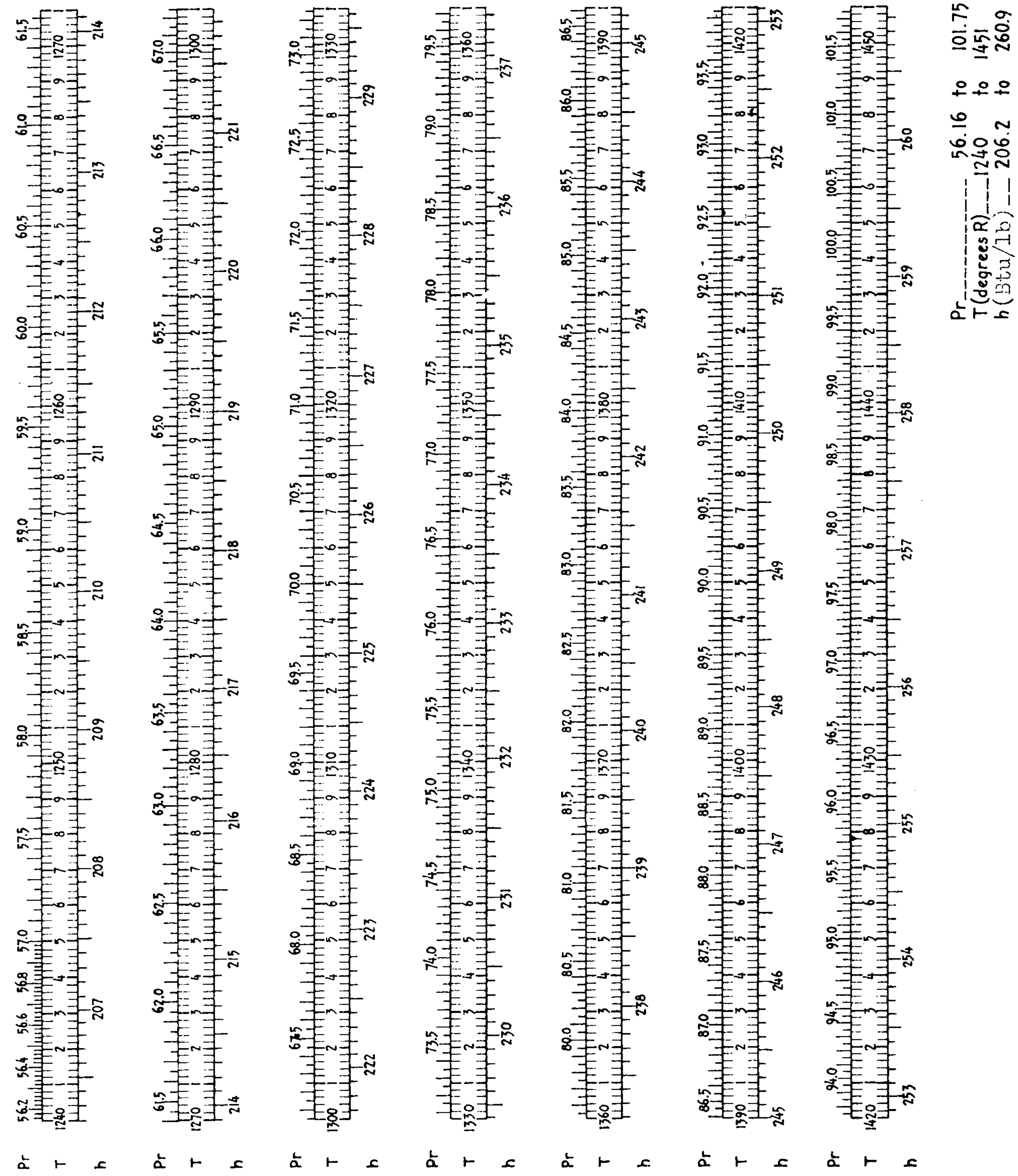
Pr	1.00	to	4.41
T (degrees R)	400	to	611
h (Btu/lb)	0.0	to	50.7

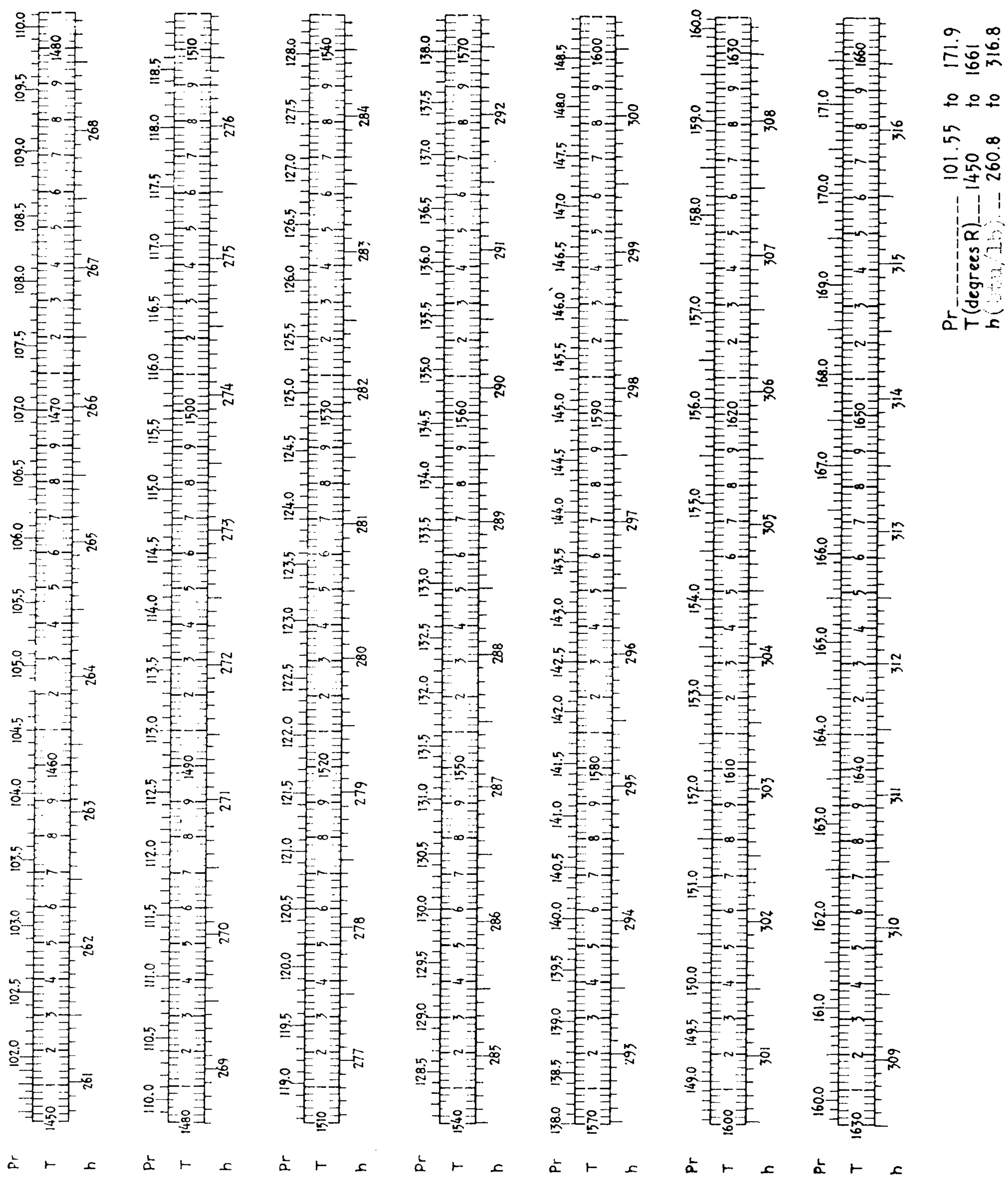

Pr 4.39 to 12.52
T (degrees R) 610 to 821
h (Btu/lb) 50.5 to 101.5

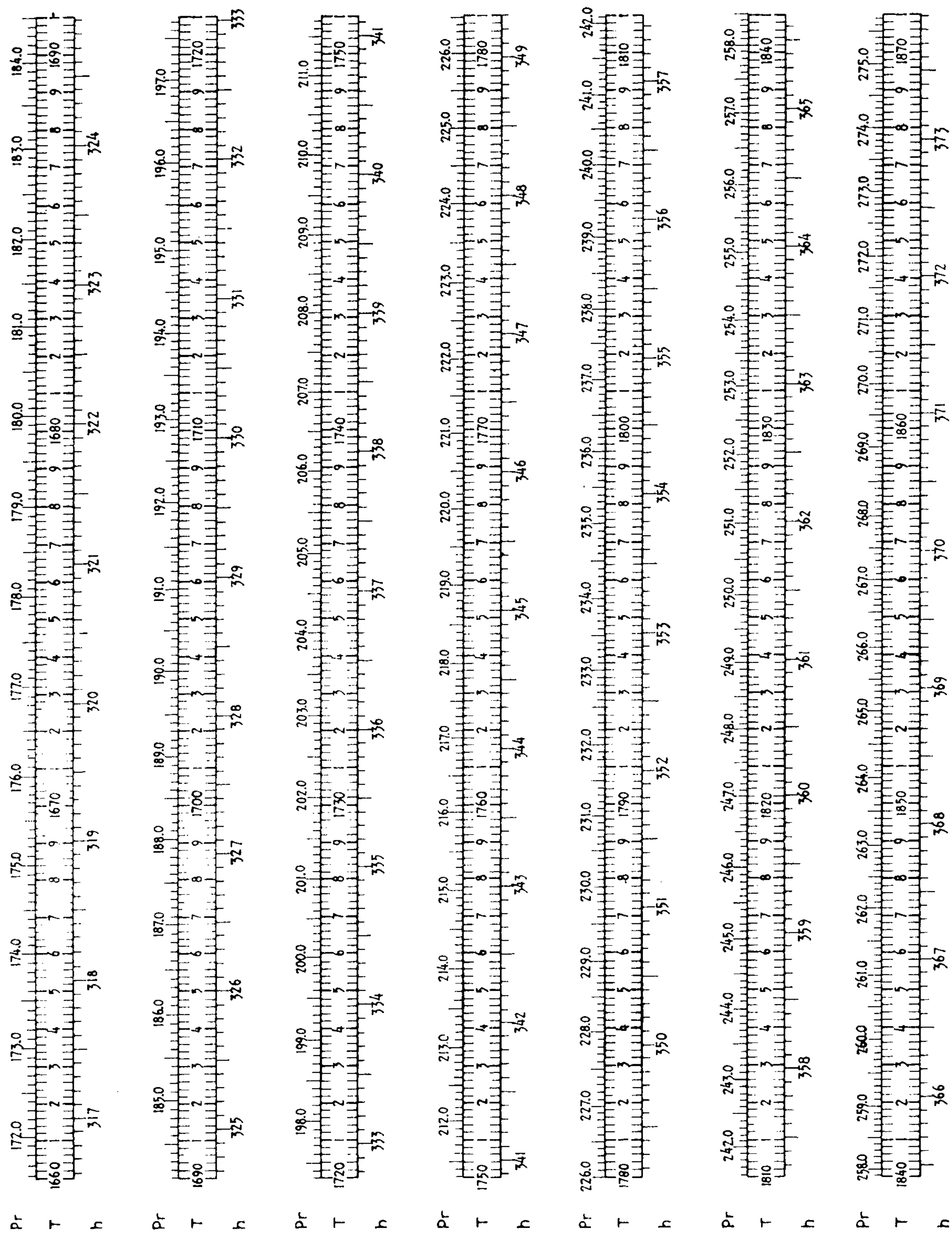


Pr ---------- 12.48 to 28.42
T(degrees R) --- 820 to 1031
h(Btu/lb) --- 101.3 to 153.3

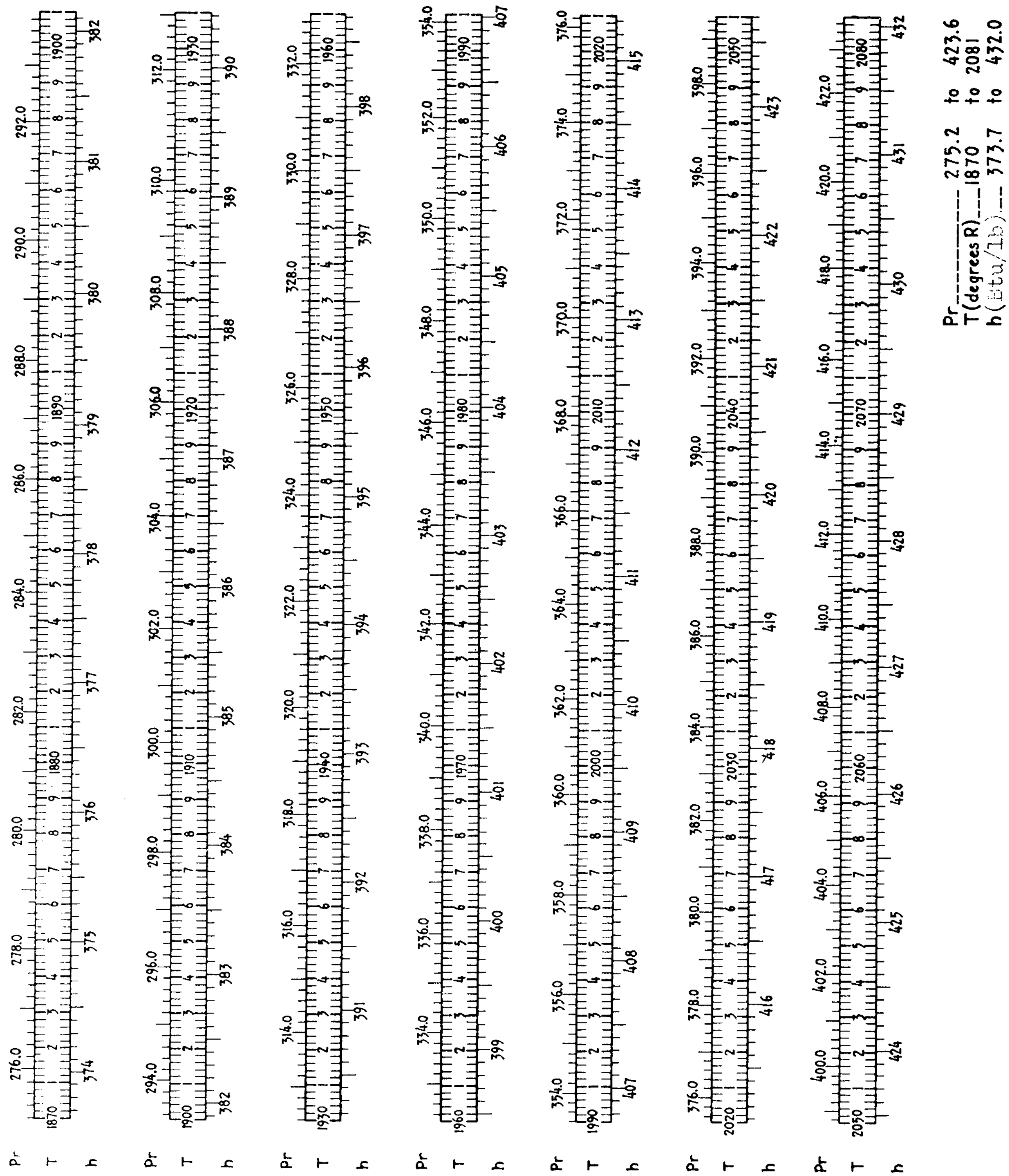

Pr 28.32 to 56.32
T (degrees R) 1030 to 1241
h (Btu/lb) 153.1 to 206.4

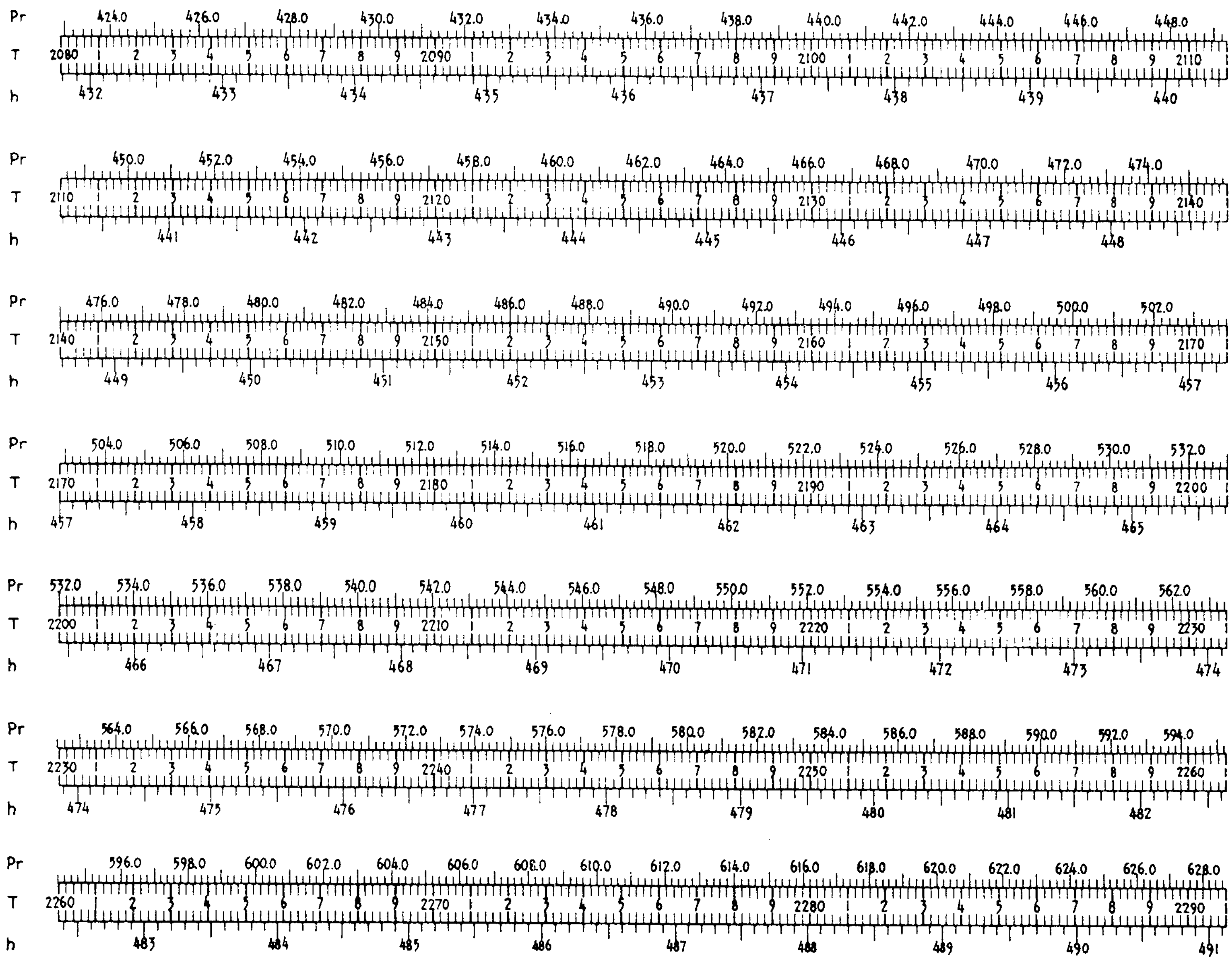

Pr 56.16 to 101.75
T(degrees R) 1240 to 1451
h(Btu/lb) 206.2 to 260.9


Pr 101.55 to 171.9
T(degrees R) 1450 to 1661
h 260.8 to 316.8

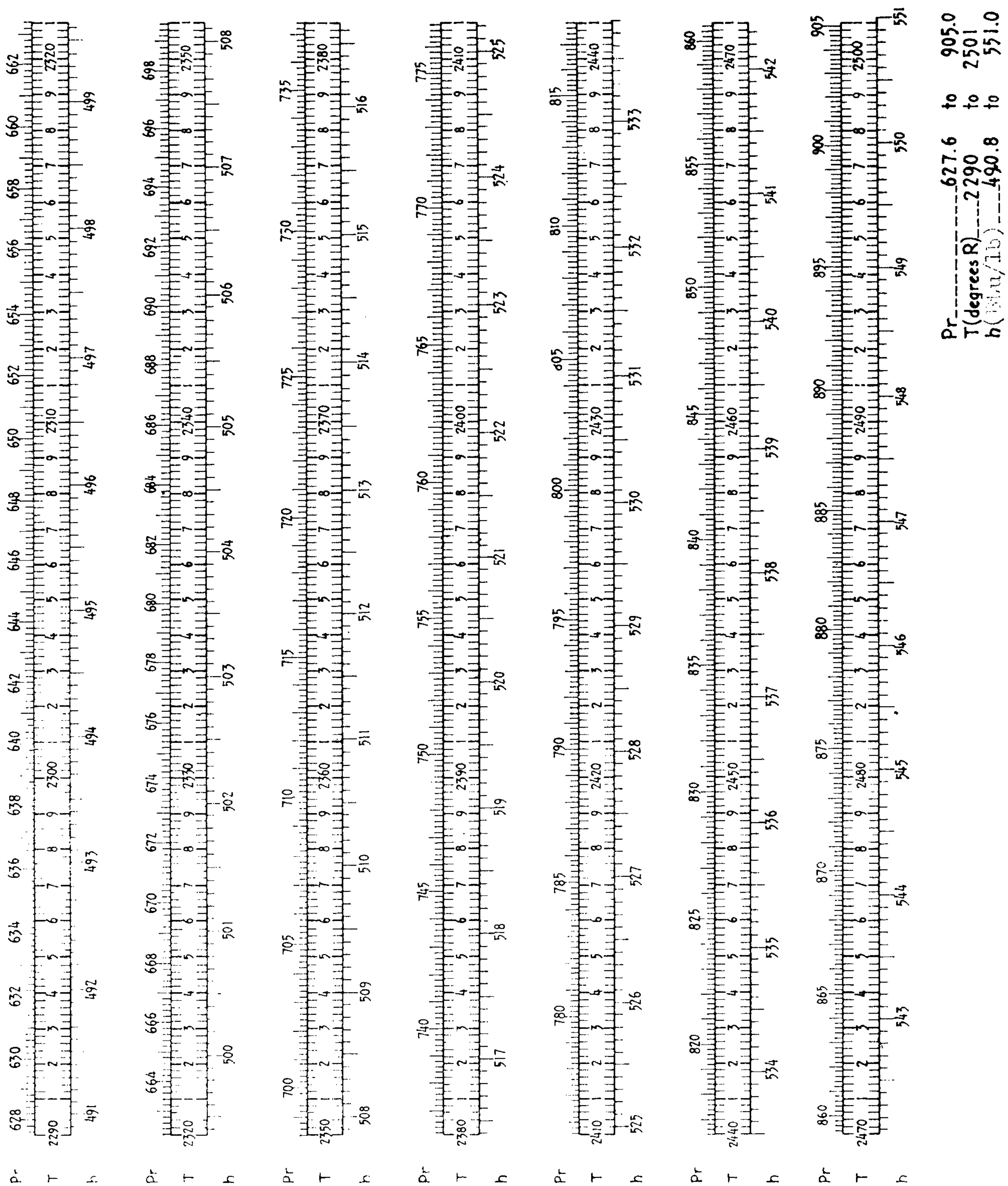


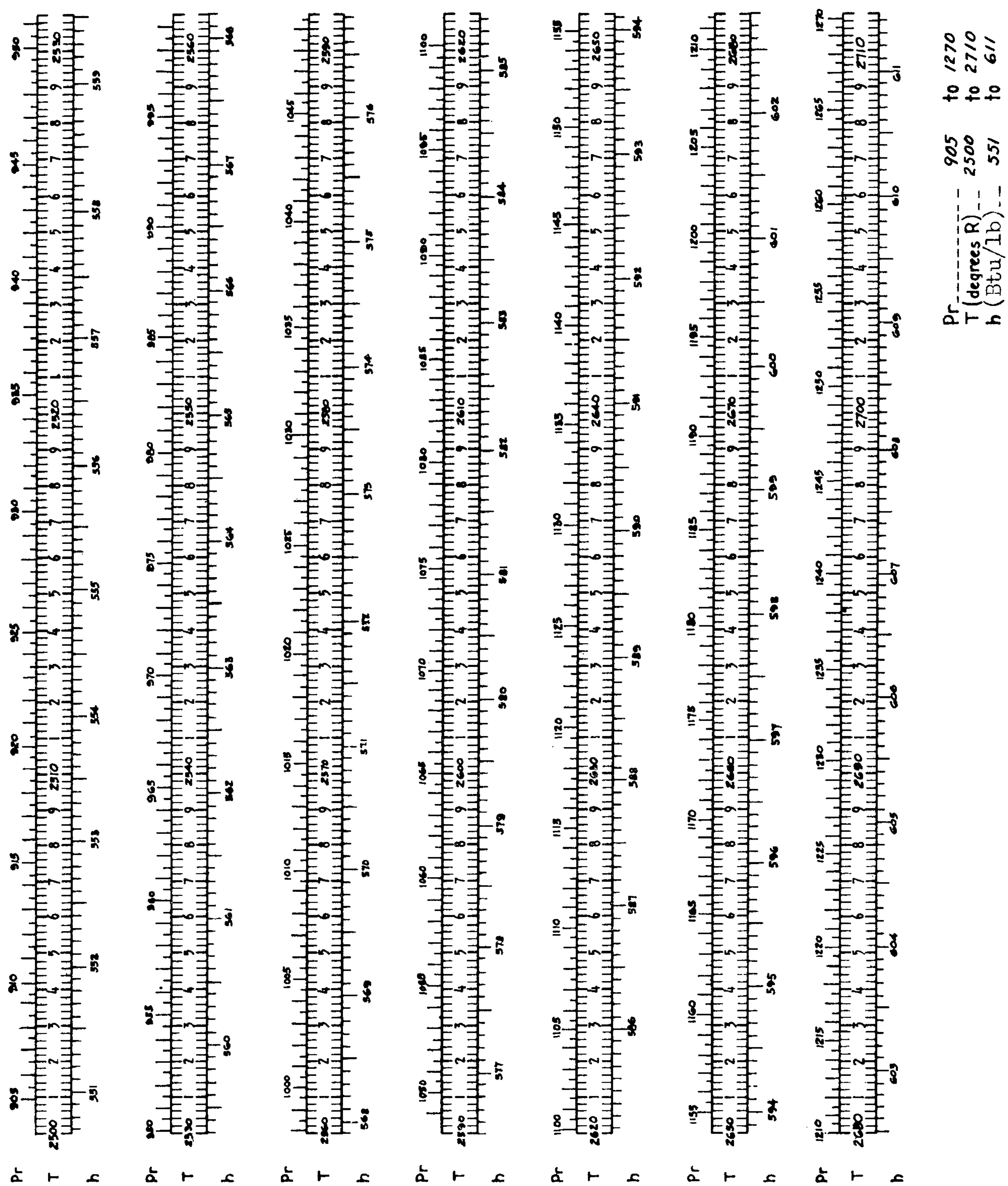
Pr ---------- 171.6 to 275.7
T (degrees R) ---- 1660 to 1871
h (Btu/lb) ---- 316.5 to 373.9

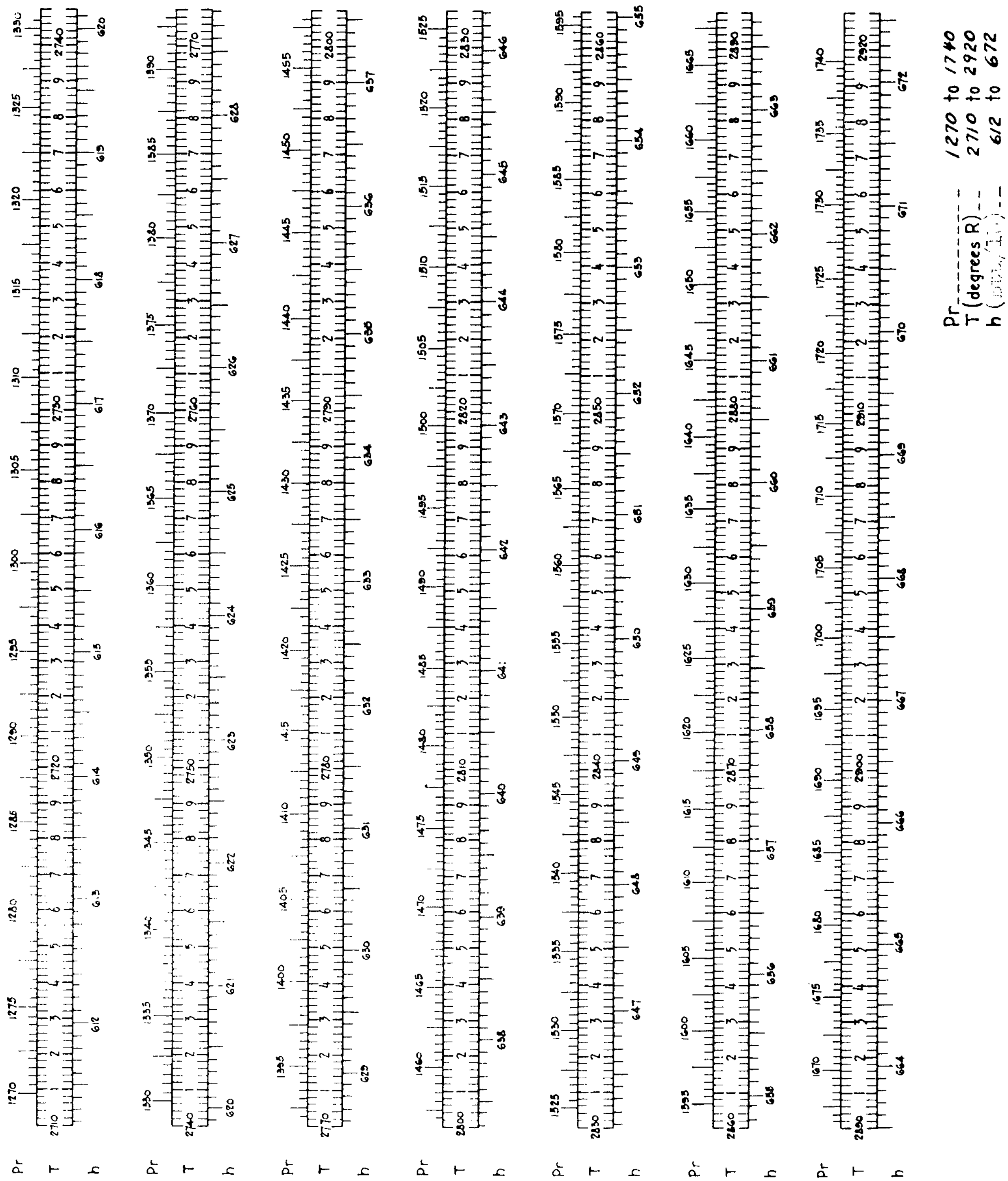

Pr ______ 275.2 to 423.6
T (degrees R) ___ 1870 to 2081
h (Btu/lb) ___ 373.7 to 432.0

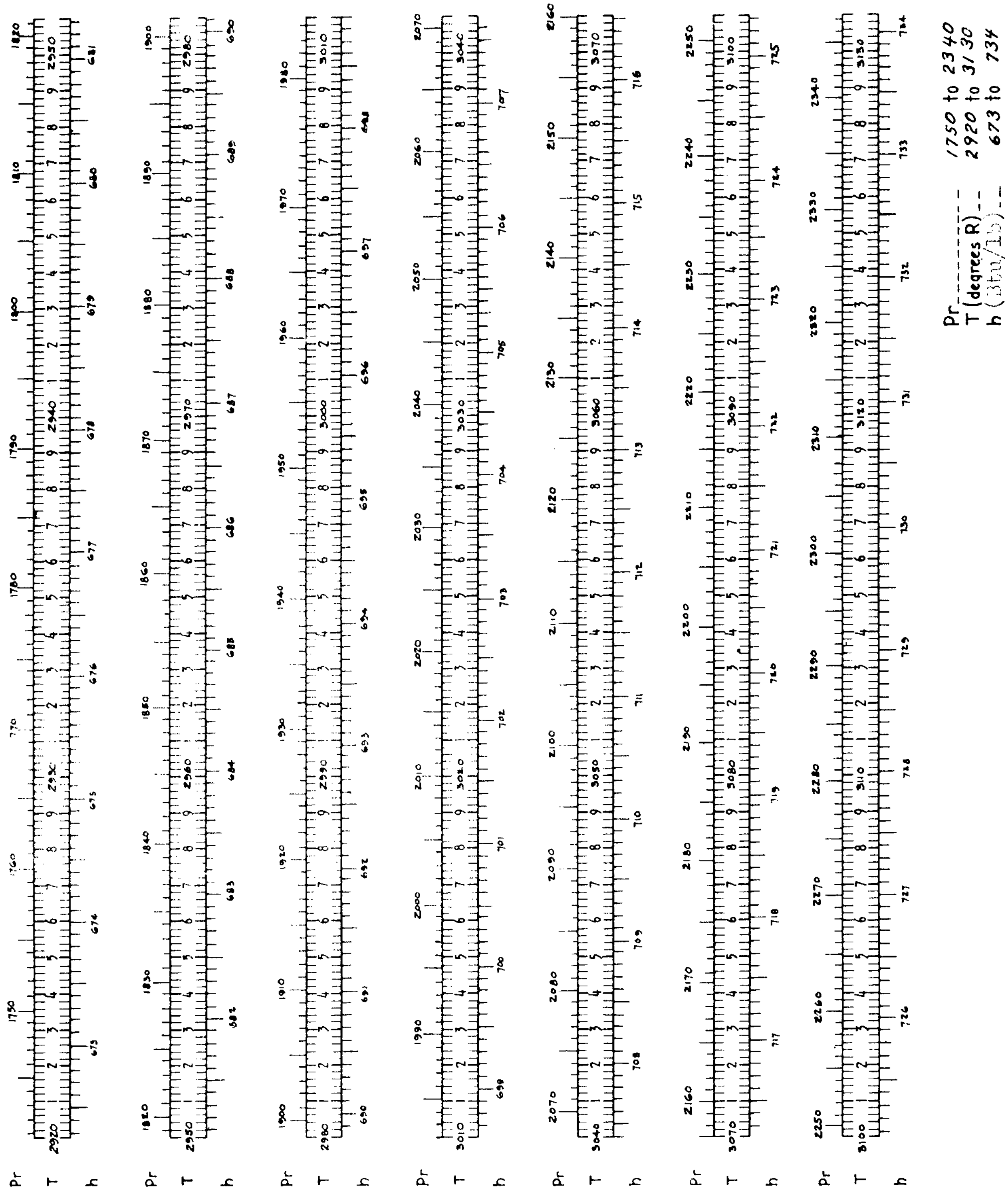


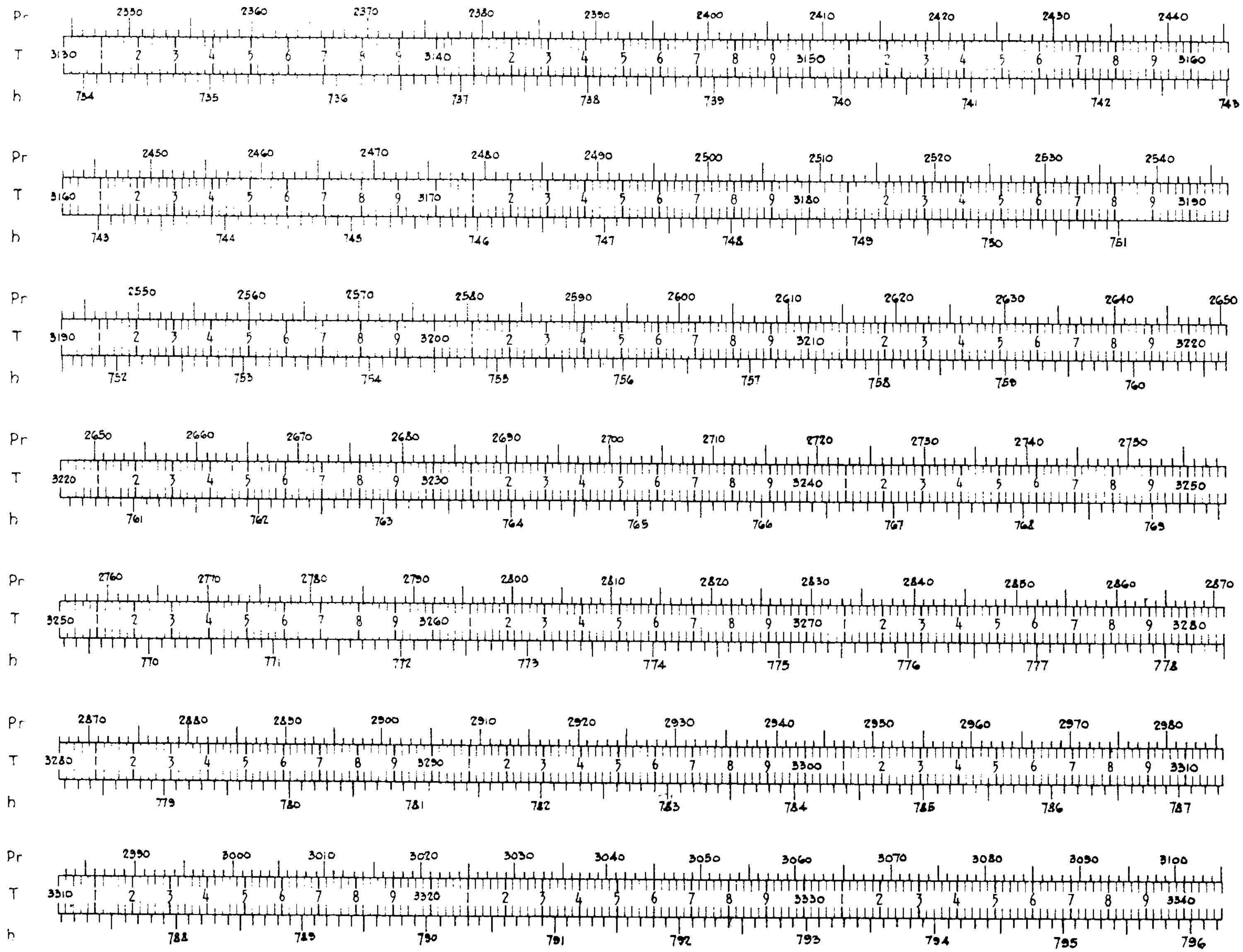
Pr ---------- 423.0 to 628.6
T (degrees R) --- 2080 to 2291
h (Btu/lb) --- 431.8 to 491.1


Pr 627.6 to 905.0
T(degrees R) 2290 to 2501
h(Btu/lb) 490.8 to 551.0

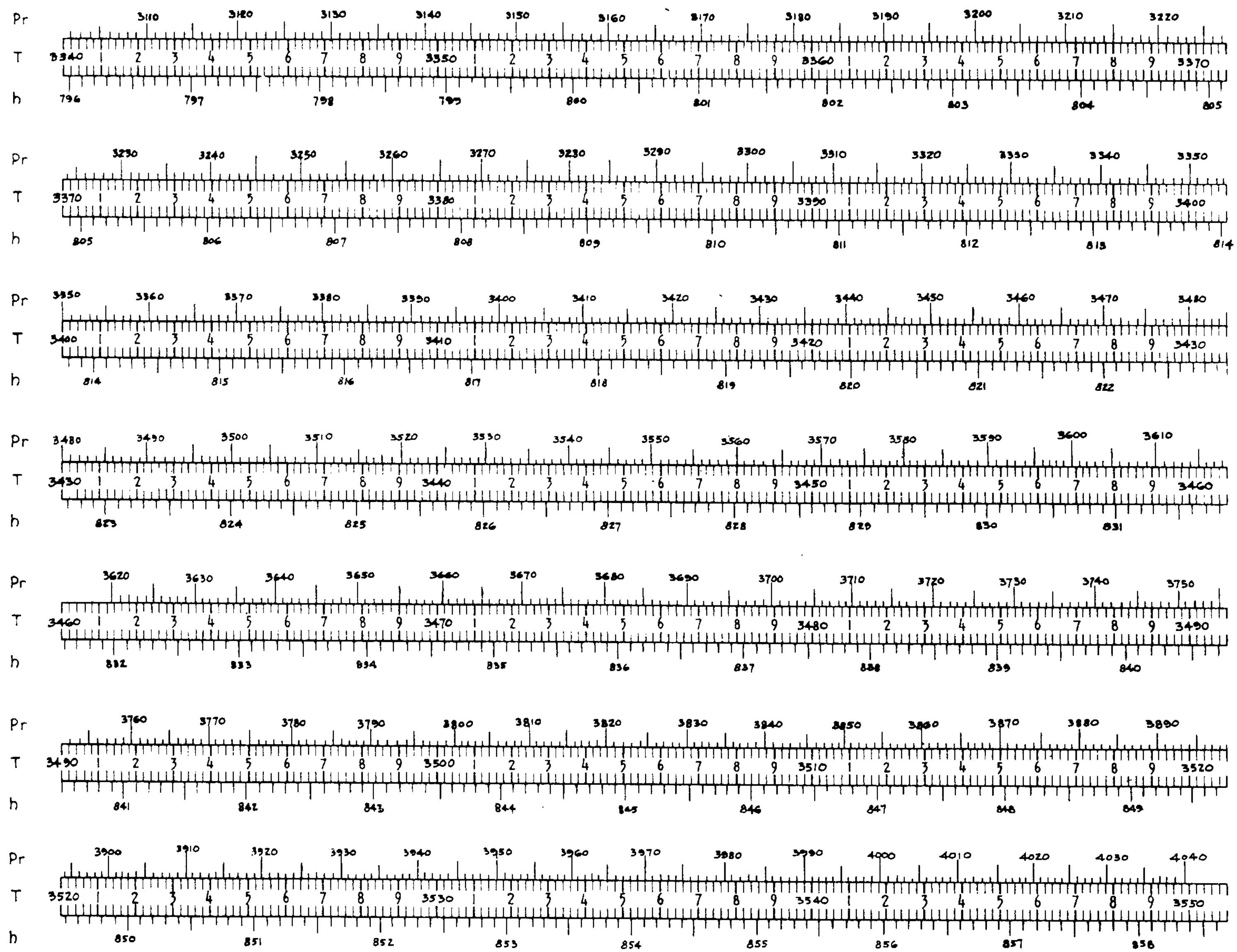

Pr------------ 905 to 1270
T (degrees R)-- 2500 to 2710
h (Btu/lb)-- 551 to 611


Pr 1270 to 1740
T (degrees R) 2710 to 2920
h 612 to 672

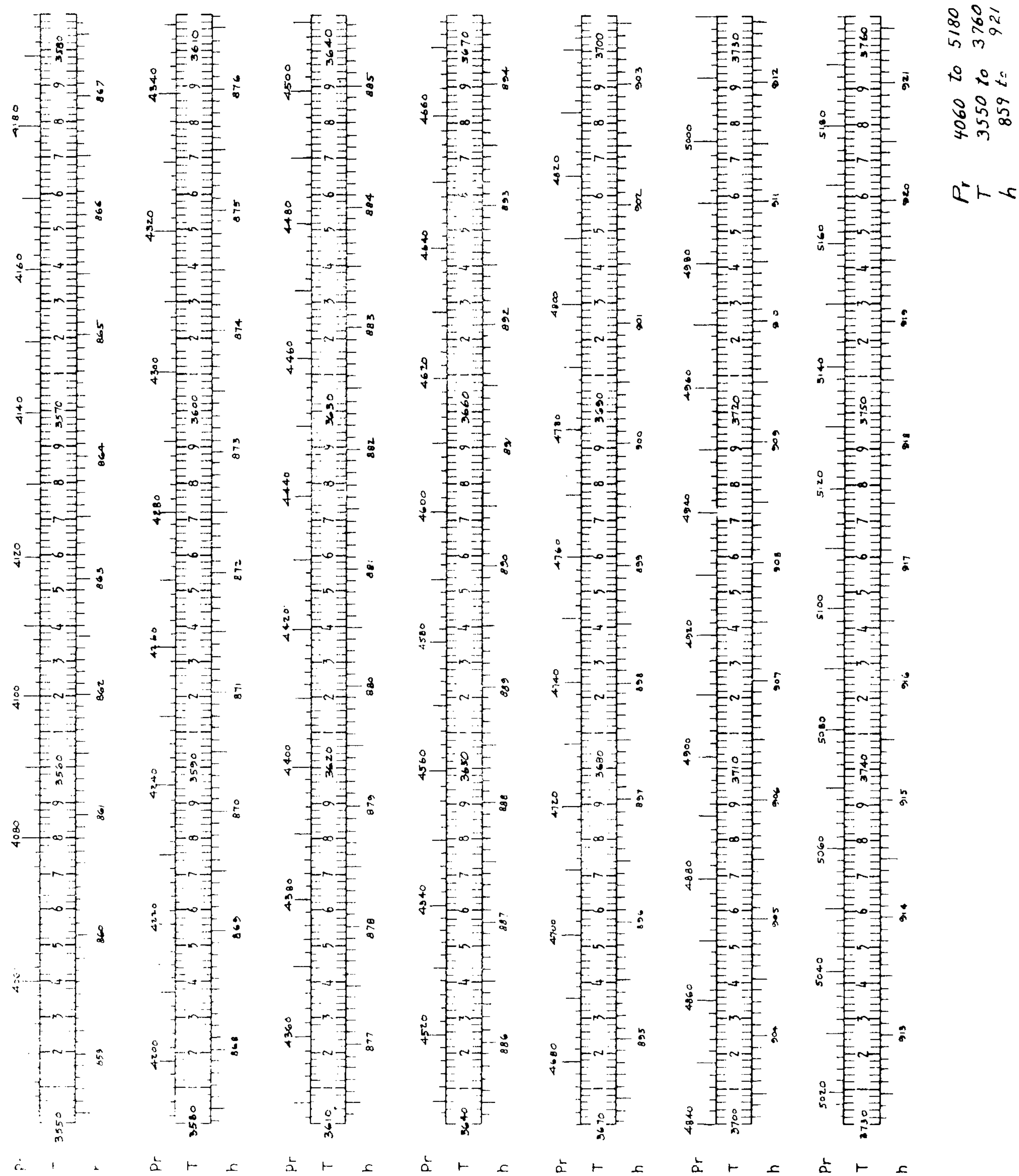

Pr ---------- 1750 to 2340
T (degrees R) -- 2920 to 3130
h (Btu/lb) -- 673 to 734

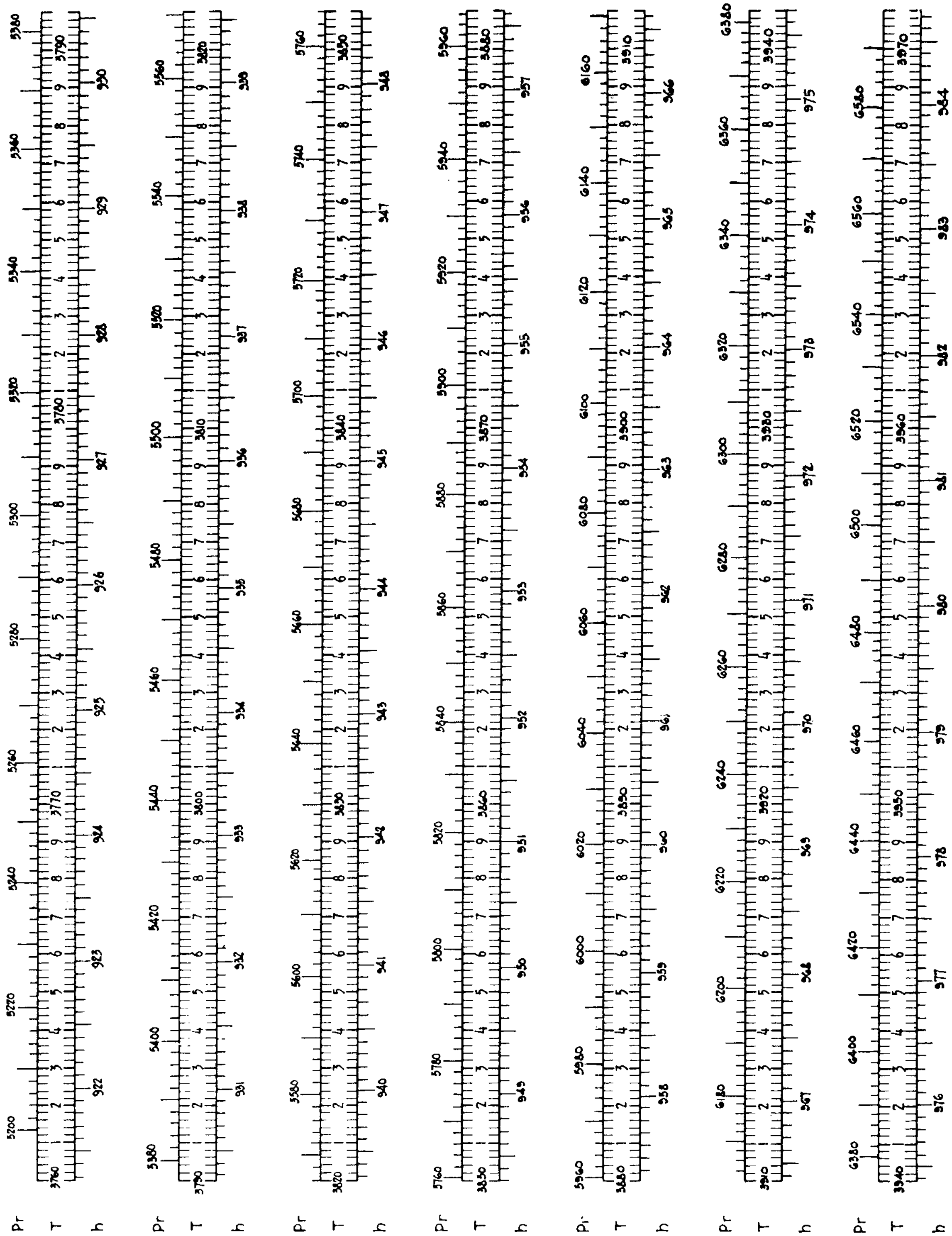


Pr - - - - - - - - - - 2350 to 3100
T (degrees R) - - 3130 to 3340
h (Btu/lb) - - - 734 to 796

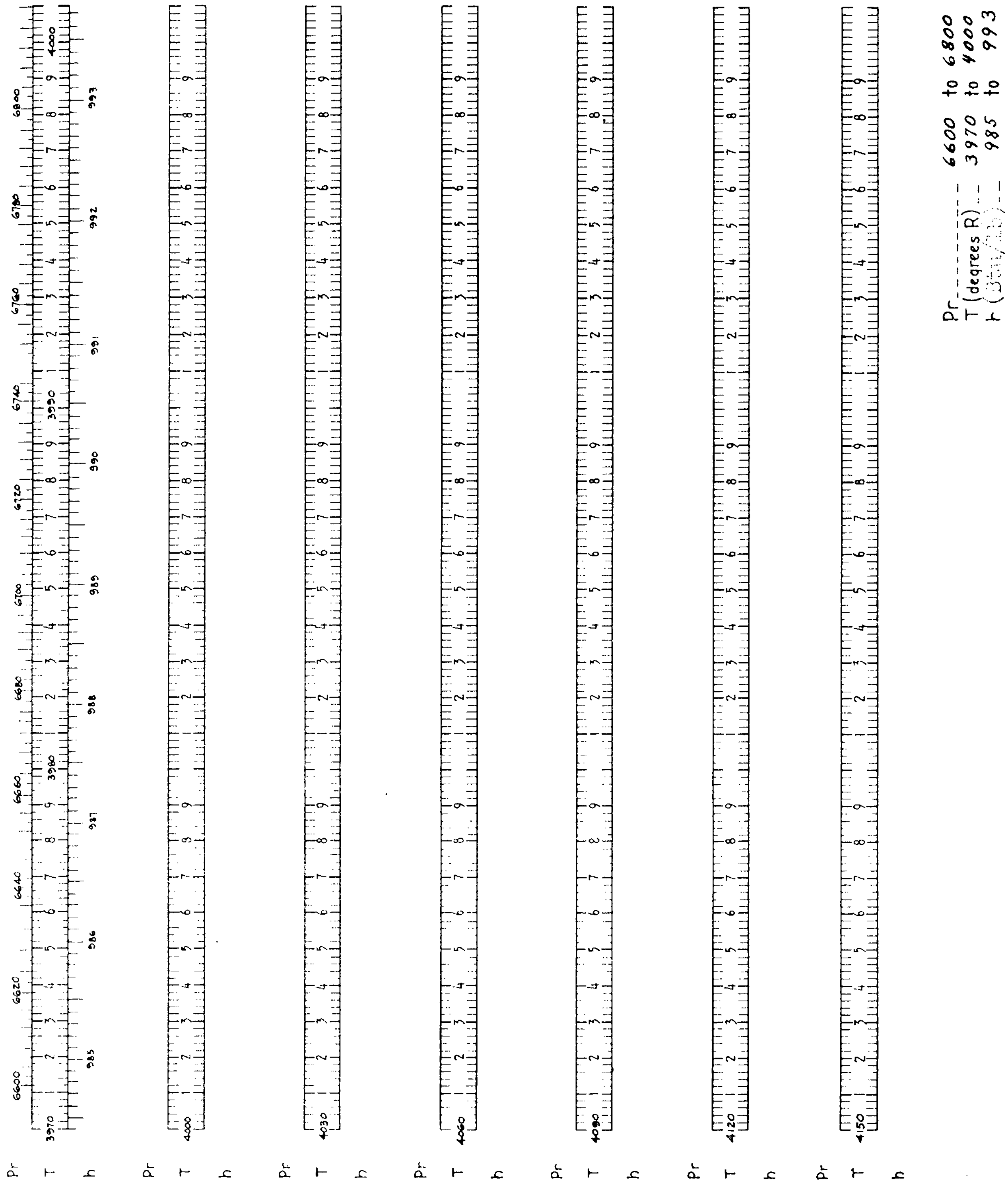


Pr ---------- 3110 to 4040
T (degrees R) -- 3340 to 3550
h (Btu/lb) -- 796 to 858


P_r 4060 to 5180
T 3550 to 3760
h 859 to 921



Pr ---------- 5200 to 6580
T (degrees R) -- 3760 to 3970
h (Btu/lb) -- 922 to 984


Pr - 6600 to 6800
T (degrees R) - 3970 to 4000
h (Btu/lb) - 985 to 993

Physical Properties of Air

Introduction

Data reported by many investigators are in good agreement concerning the physical properties of air as a function of temperature. These physical properties are listed in Table 2 and are plotted in Figures 1A and 1B. A specific exception is thermal conductivity data at high temperatures. In this case few experimental data are available. The Aircraft Nuclear Propulsion Department standards have been based on experimental data of Stops.* Recent data and extrapolations by many workers have tended to confirm these data. The present standards of the National Bureau of Standards are also in close agreement with these data.

In most engineering calculations air can be treated as an ideal gas, and its physical properties may be assumed to be independent of pressure level. Significant exceptions may occur at extremely low temperatures in conjunction with either low pressures (vacuum) or extremely high pressures (above 5000 psi). The National Bureau of Standards work or any engineering thermodynamics text can be used to determine whether the deviations from ideality are of concern.

In precise calculations it may be necessary to consider the nonideal behavior of air, the effect of water vapor on physical properties and density, and dissociation effects at high temperatures. A limited coverage of the various items mentioned is presented and detailed evaluations are available in the references cited.

Water Vapor

Atmospheric air contains small amounts of water vapor; however, the moisture content is usually sufficiently low that assumption of applicability of dry-air properties is valid. For extreme precision it may be necessary to weight physical properties in proportion to relative amounts of air and water present. Data for specific heat of moist air calculated in this manner is tabulated and reproduced.† Dry-air specific-heat data are not usually applicable to the definition of temperatures during cooling of moist air if water vapor is condensed by the cooling process. Data for such processes are available in standard psychometric charts.

Nonideal Behavior of Air

Data pertinent to nonideal behavior of air are largely defined by methods of statistical thermodynamics. The generalized compressibility chart, Figure 2, derived from such work illustrates conveniently the ranges in which air can be expected to behave in a

*D. W. Stops, *Nature*, Vol. 164, pp. 966–967, 1947.

†J. O. Hirschfelder, C. F. Curtiss, Report CM-518, 1948; *The Reactor Handbook*, AECD 3646, 1955, p. 383–4.

TABLE 2

PHYSICAL PROPERTIES OF DRY AIR AT ATMOSPHERIC PRESSURE[a]

T, °R	t, °F	C_p, Btu/lb-°F	C_v, Btu/lb-°F	$\gamma = \frac{C_p}{C_v}$	a, ft/sec	$\mu \times 10^7$, lbm/sec-ft	K, Btu/hr-ft-°F	$\frac{3600\, C_p \mu}{K}$ P_r
100	-359.7	0.2392	0.1707	1.402	490.5		0.00236	
150	-309.7	0.2392	0.1707	1.402	600.7		0.00391	
200	-259.7	0.2392	0.1707	1.402	693.6		0.00590	
250	-209.7	0.2392	0.1707	1.402	775.4		0.00705	
300	-159.7	0.2392	0.1707	1.402	849.4		0.00856	
350	-109.7	0.2393	0.1707	1.402	917.5		0.01003	
400	- 59.7	0.2393	0.1707	1.402	980.9	100	0.01145	0.752
450	- 9.3	0.2394	0.1708	1.401	1040.3	109	0.01283	0.732
500	40.3	0.2396	0.1710	1.401	1096.4	118	0.01415	0.719
550	90.3	0.2399	0.1713	1.400	1149.6	126	0.01543	0.705
600	140.3	0.2403	0.1718	1.399	1200.3	135	0.01667	0.701
650	190.3	0.2409	0.1723	1.398	1248.7	143	0.01786	0.694
700	240.3	0.2416	0.1730	1.396	1295.1	151	0.01903	0.690
750	290.3	0.2424	0.1739	1.394	1339.6	158	0.02015	0.684
800	340.3	0.2434	0.1748	1.392	1382.5	166	0.02125	0.684
900	440.3	0.2458	0.1772	1.387	1463.6	179	0.02334	0.679
1000	540.3	0.2486	0.1800	1.381	1539.4	192	0.02533	0.678
1100	640.3	0.2516	0.1830	1.374	1610.8	205	0.02722	0.682
1200	740.3	0.2547	0.1862	1.368	1678.6	218	0.02904	0.688
1300	840.3	0.2579	0.1894	1.362	1743.2	230	0.03077	0.694
1400	940.3	0.2611	0.1926	1.356	1805.0	242	0.03243	0.701
1500	1040.3	0.2642	0.1956	1.350	1864.5	253	0.03404	0.707
1600	1140.3	0.2671	0.1985	1.345	1922.0	264	0.03559	0.713
1700	1240.3	0.2698	0.2013	1.340	1977.6	274	0.03708	0.718
1800	1340.3	0.2725	0.2039	1.336	2032	284	0.03854	0.723
1900	1440.3	0.2750	0.2064	1.332	2084	293	0.03995	0.726
2000	1540.3	0.2773	0.2088	1.328	2135	302	0.04131	0.730
2100	1640.3	0.2794	0.2109	1.325	2185	311	0.04264	0.734
2200	1740.3	0.2813	0.2128	1.322	2234	320	0.04395	0.737
2300	1840.3	0.2831	0.2146	1.319	2282	329	0.04521	0.742
2400	1940.3	0.2848	0.2162	1.317	2329	338	0.04645	0.746
2600	2140.3	0.2878	0.2192	1.313	2420		0.04884	
2800	2340.3	0.2905	0.2219	1.309	2508		0.05113	
3000	2540.3	0.2929	0.2243	1.306	2593		0.05332	
3200	2740.3	0.2950	0.2264	1.303	2675		0.05544	
3400	2940.3	0.2969	0.2283	1.300	2755		0.05751	
3600	3140.3	0.2986	0.2300	1.298	2832		0.05948	
3800	3340.3	0.3001	0.2316	1.296	2907		0.06139	

[a]Reprinted with permission from Keenan and Kaye, Gas Tables, 1945, John Wiley & Sons, Inc.

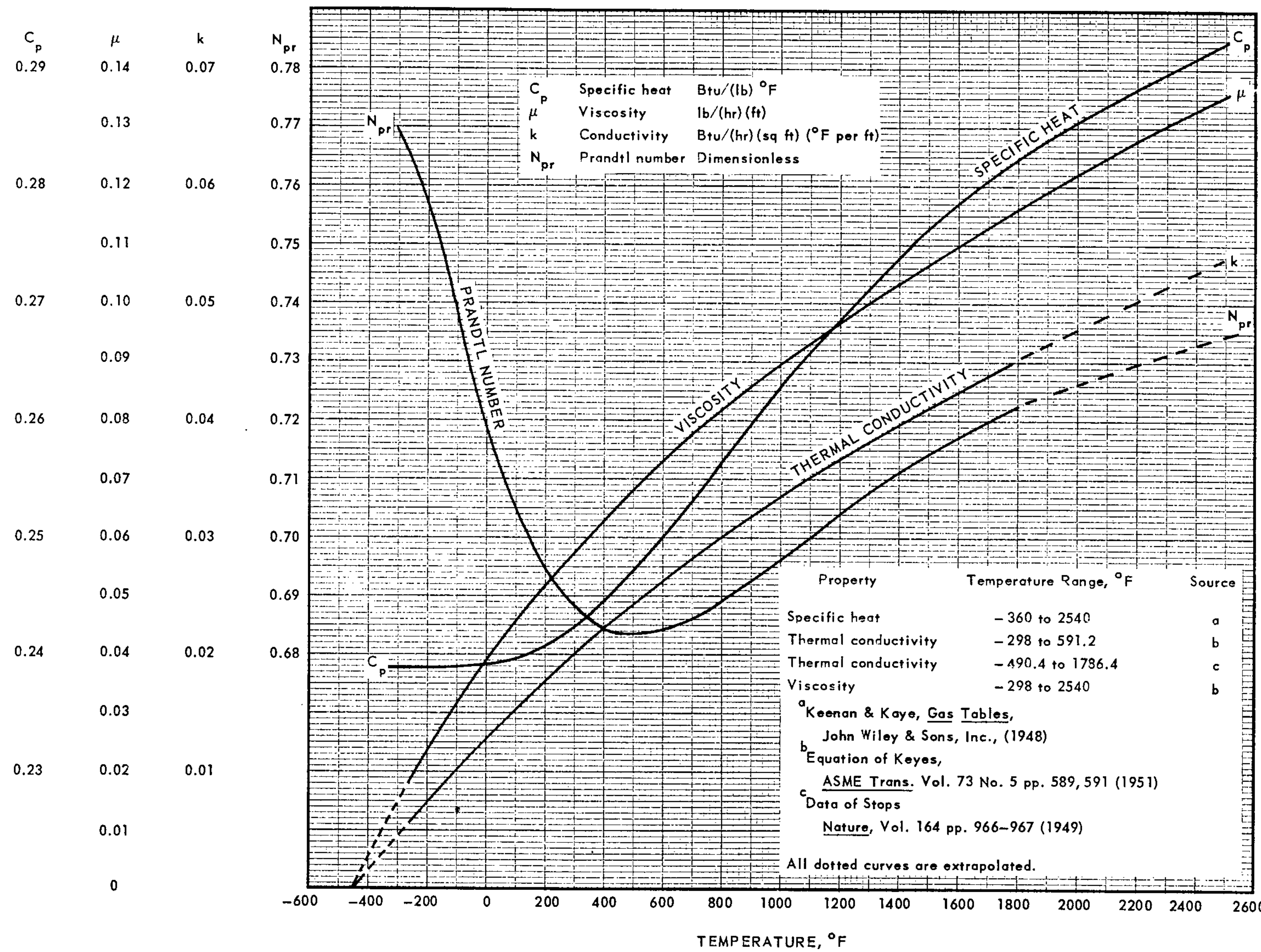


Fig. 1A – Physical properties of air

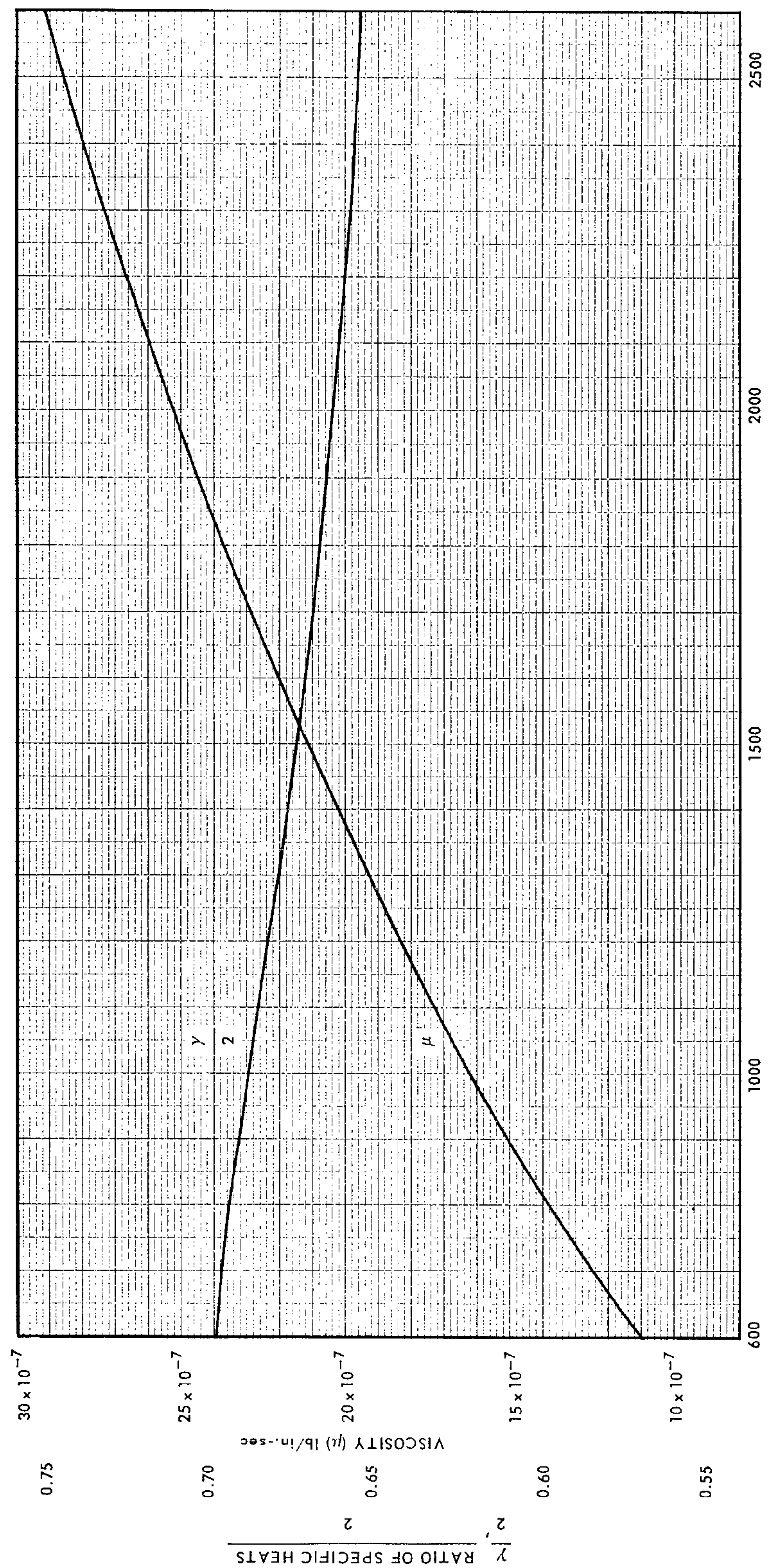


Fig. 1B – Physical properties of air
(Data Source: Keenan and Kaye *Gas Tables*)

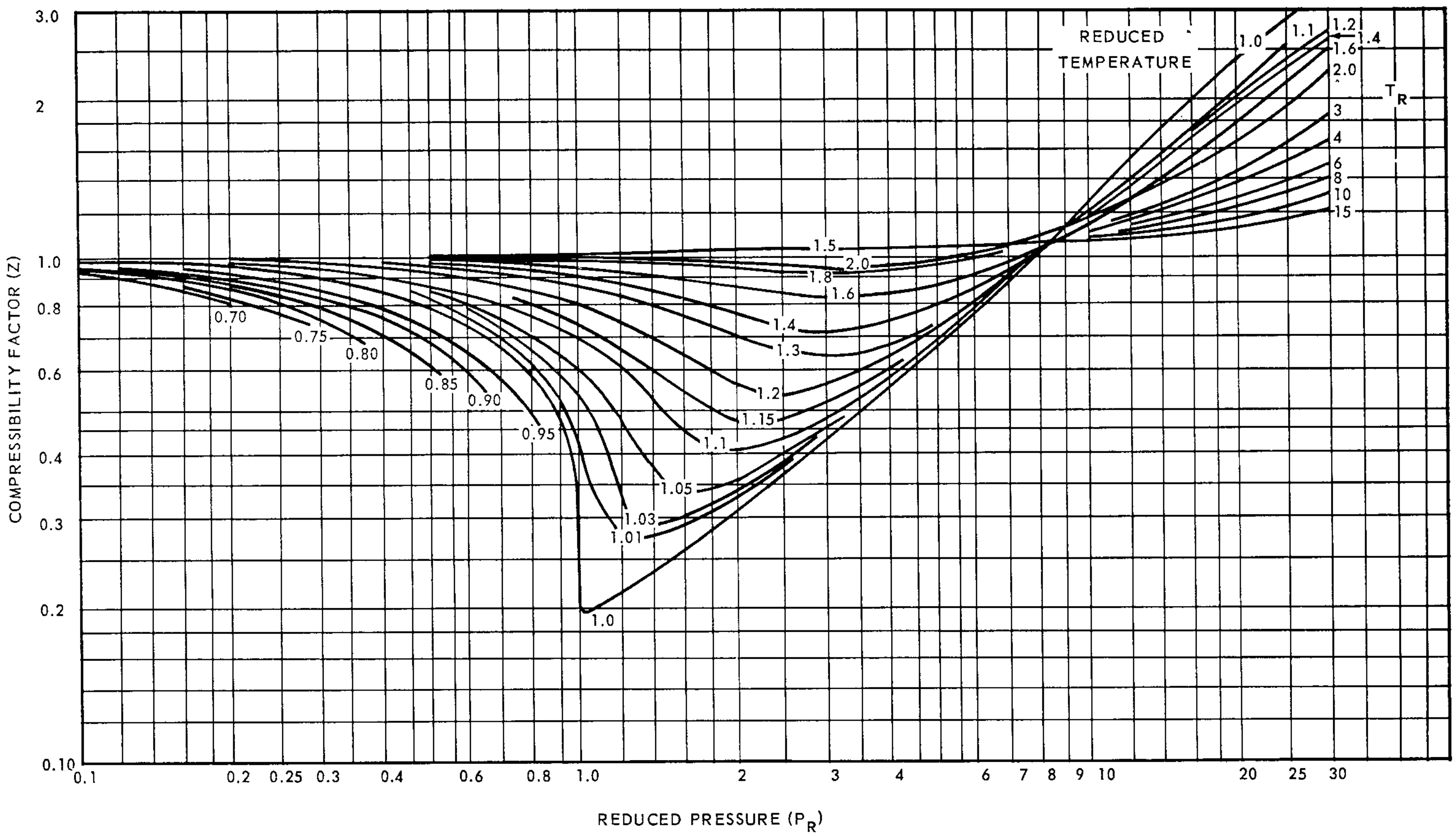


Fig. 2 – Compressibility factor for gases

nonideal manner. The chart is a plot of compressibility factor (Z) versus reduced pressure (p_r) with reduced temperature (T_r) as a parameter. The various terms are defined as follows:

$Z = \frac{pV}{RT}$	Z = 1 for ideal gas
$T_r = T/T_c$	T - absolute temperature
$p_r = p/p_c$	p - absolute static pressure
	Subscript c - critical

For air:

$T_c = 238.55^\circ R,\ 132.53^\circ K$

$p_c = 546.25$ psi, 37.17 atm

From the chart and critical-property data it is readily apparent that air behaves essentially as an ideal gas except at extremely high pressures and extremely low temperatures. The compressibility chart, although intended for illustrative purposes, can be used to estimate deviation of air from ideal-gas behavior. A complete presentation of nonideal behavior of air is available.*

Similar charts are available for specific heat, entropy, viscosity, and thermal conductivity,† although only the charts for specific heat and entropy are developed sufficiently to be reliable. In all of these works it is indicated that physical properties become pressure insensitive as reduced temperature increases, and that correction factors are essentially negligible for air except at the extremes noted for compressibility factor variation. A detailed calculation of pressure effect on specific heat is available.‡

Dissociation

Dissociation of air (conversion of molecular to atomic species) does not normally affect engineering considerations of air properties at temperatures below 2400°F with subatmospheric pressures, or temperatures in excess of 4000°F with greater-than-atmospheric pressures. The atom species present in air at atmospheric pressure, and temperatures up to 5000°F account for less than 1.5 percent of the total atomic and molecular species present. Hence, it could be anticipated that physical properties are essentially independent of dissociation up to this temperature level. An important exception concerns interpretation of heat-capacity data. The usual definition of heat capacity applies to a material whose composition remains constant over a unit temperature interval, and is expressed by the relation:

$$\left(\frac{dH}{dT}\right)_p = C_p$$

in which

C_p = Heat capacity

$(dH/dT)_p$ = Change of enthalpy with respect to temperature at constant pressure.

When a diatomic gas dissociates, the enthalpy change for an interval of temperature would be expressed by the relation

$$\frac{dH}{dT} \cong a\,\Delta H_D + (1 - a)\,C_{p_M} + 2a\,(C_{p_A})$$

*"Tables of Thermal Properties of Gases," Circular No. 564, National Bureau of Standards, November 1955, and N. A. Hall, W. E. Ibele, *Transactions ASME*, 76, 1039, 1954.

†O. A. Haugen, K. M. Watson, *Chemical Process Principles*, Vol. II, John Wiley and Sons, Inc., New York, 1943. "Reaction Kinetics and Transfer Process," Chemical Engineering Progress Symposium Series No. 4.

‡"Table of Thermal Properties of Gases," Reference 10.

in which

a = Fraction of molecular species dissociated

C_{p_M} = Heat capacity of molecular species

C_{p_A} = Heat capacity of atomic species

ΔH_D = Heat of dissociation

Since ΔH_D is usually several thousand times the magnitude of C_{p_M}, even small degrees of dissociation can significantly affect the total enthalpy change. Most references combine all of the right-hand terms of the preceding equation in the form of an apparent heat capacity. Since the degree of dissociation of air is a function of both pressure and temperature, this apparent heat capacity is pressure sensitive at temperature levels where dissociation can occur; the pressure sensitivity is, however, a measure of the degree of dissociation rather than of the nonideal behavior of air. Data applicable to dissociation calculations for air is presented in Wooley.*

Water Content of Compressed Air

Compressed air or gas usually contains some water vapor. The amount of moisture contained depends upon (1) the condition of air at the compressor inlet, (2) the compression system, and (3) the degree of aftercooling. Stationary compressors are generally equipped with aftercoolers (water-cooled heat exchangers) to decrease water content by cooling the compressed gas. The maximum amount of water vapor contained in air corresponds to the equilibrium or saturation concentration, which is, in turn, a function of temperature and pressure. Maximum concentrations of water vapor in air can be estimated by use of Dalton's law. However, water vapor - air mixtures do not behave as ideal gases. Figure 3 based on the work of Landsbaum and coworkers,† presents the nonideal behavior of air-water mixtures. This figure represents experimental data for most of the temperature range up to pressures of 200 atmospheres. The remainder of the curve is extrapolated. The effectiveness of aftercooling (decrease of compressed-air temperature) is readily apparent.

Water Content of Atmospheric Air

Moisture content of atmospheric air varies greatly from day to day, and the range of variation is different for different locations. Average absolute moisture content, expressed as pounds of water per pound of dry air, varies from about 0.01 at sea level to 0.00001 at 35,000 feet; the range of variation about these averages decreases with increasing altitude.

Rain ingestion at compressor inlets can increase water content of air. The amount of increase is largely a function of both type and exposure of compressor inlet. Stationary compressors would not normally be expected to ingest rain, whereas airborne systems would. Heavy rain corresponds to absolute water (as drops) content of 0.01 to 0.05 pound of water per pound of dry air, the usual rains being associated with the lower value or less.

Empirical Equations

The empirical equations contained in this section have been derived from data presented elsewhere in this book. The usefulness of the equations is in the adaptability to IBM digital computations. The error ascribed to the air-properties relations within the given limits

*H. W. Wooley, "Effect of Dissociation on Thermodynamic Properties of Pure Diatomic Gases," NACA Report TN 3270, 1955.

†E. M. Landsbaum, et al, *Industrial Engineering Chemistry*, Vol. 47, p. 102, 1955.

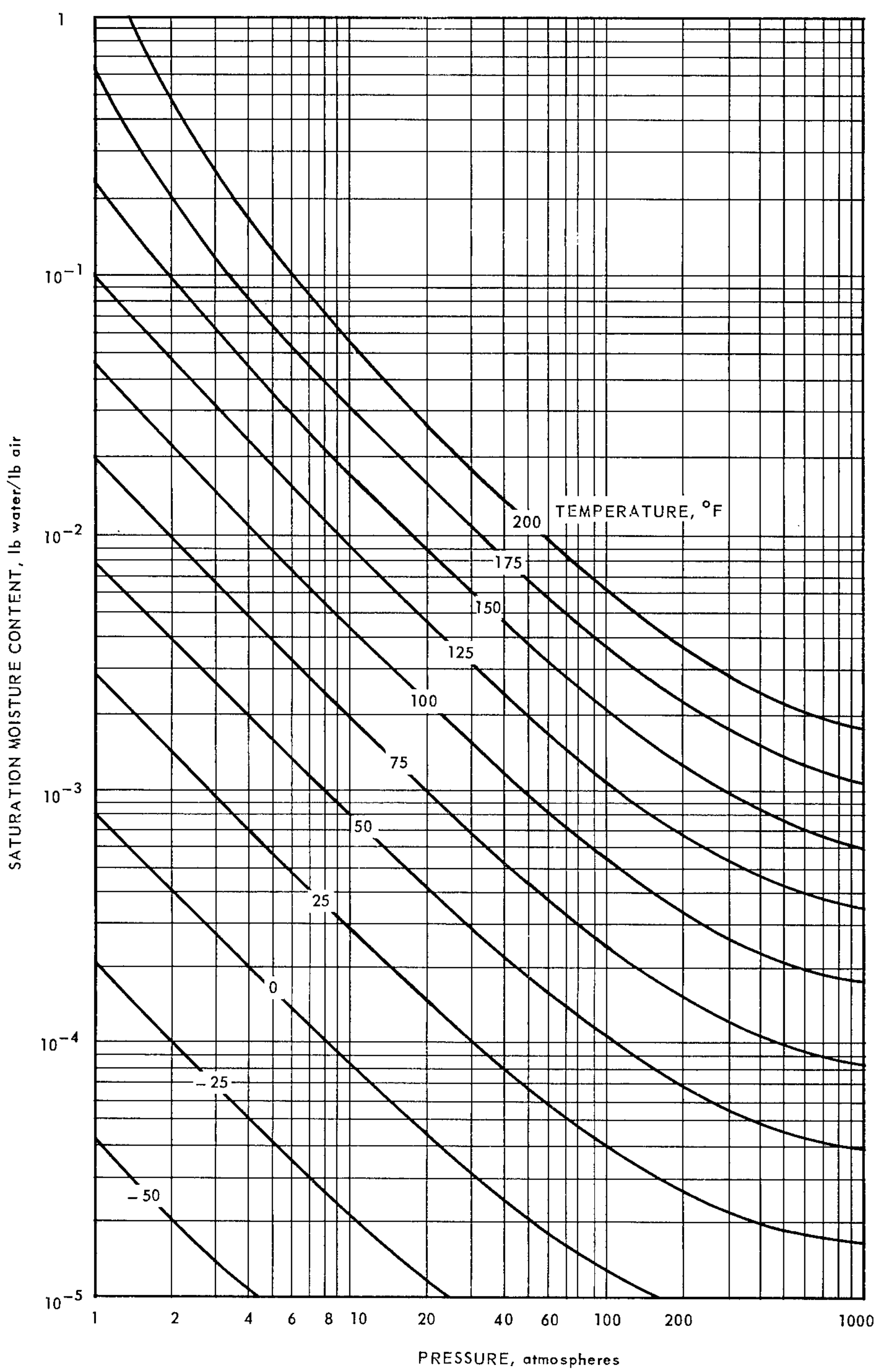


Fig. 3 – Saturation moisture content of air as a function of temperature and pressure (Data Source: Landsbaum, E.M. et al., *Ind. Engg. Chem.*, 47, 102, (1955).)

is less than 1 percent. This error is well within the limits in which the properties are known. Units are given in the foot-pound-sec, ^{o}R system.

	Range of Application
1. $\gamma = C_p/C_v = 1.3817 + 1.05 \times 10^{-4}\ T - 1.629 \times 10^{-7}\ T^2 + 6.572 \times 10^{-11}\ T^3 - 8.645 \times 10^{-15}\ T^4$	$500^o - 2900^oR$
2. $\mu = (23.25 + 0.21365\ T - 5.004 \times 10^{-5}\ T^2 + 6.967 \times 10^{-9}\ T^3 - 2.588 \times 10^{-13}\ T^4) \times 10^{-7}$	$500^o - 2900^oR$
3. $C_p = 0.2479 - 4.5292 \times 10^{-5}\ T + 6.8267 \times 10^{-8}\ T^2 - 2.5216 \times 10^{-11}\ T^3 + 3.048 \times 10^{-15}\ T^4$	$500^o - 2900^oR$
4. $h = 0.240176(T) - 8.005646 \times 10^{-6}(T)^2 + 1.192176 \times 10^{-8}\ T^3 - 2.917016 \times 10^{-12}(T)^4 + 2.340132 \times 10^{-6}(T)^5$	$300^o - 4300^oR$
5. $T = 4.183639(h) + 4.440606 \times 10^{-4}(h)^2 - 3.284583 \times 10^{-6}(h)^3 + 3.74104 \times 10^{-9}(h)^4 - 1.375426 \times 10^{-12}(h)^5$	$293^o - 3930^oR$

In addition to these equations, the following relationships are reasonable engineering approximations (= ± 5 percent) for variation of physical properties of air with temperature, for the range of room temperature to 2500^oR:

1. $C_p = 0.24$ $\qquad$ $460^o - 660^oR$
2. $C_p = 0.103 \times T^{0.13}$
3. $\mu = 6.4 \times 10^{-4}\ T^{0.68}$
4. $k = 1.6 \times 10^{-4}\ T^{0.73}$

$T = {}^oRankine$ (refers to absolute total temperature)

Units: Btu, pound, foot, hour

Symbols

a = velocity of sound
C_p = specific heat of air at constant pressure
C_v = specific heat of air at constant volume
G = mass flow per unit area
h = enthalpy per unit mass
k = thermal conductivity of air
M = Mach number
T = absolute temperature
t = temperature
γ = ratio of specific heats C_p/C_v
μ = viscosity of air
P_r = Prandtl number = $C_p\ \mu/k$

The following data on composition of dry air have been established as standards by the International Civil Aviation Organization (ICAO),* as reported in NACA Report TN 3182:

COMPOSITION OF PURE DRY AIR[a]

Component	Molecular Weight	Mol. Fraction (%)	Weight (%)
Nitrogen	28.016	78.09	75.553
Oxygen	32.000	20.95	23.152
Argon	39.944	0.93	1.283
Carbon Dioxide	44.010	0.03	
Neon	20.183	1.8×10^{-3}	
Helium	4.003	5.24×10^{-4}	
Krypton	83.7	1.0×10^{-4}	
Hydrogen	2.0160	5.0×10^{-5}	$\cong 0.013$
Xenon	131.3	8.0×10^{-6}	
Ozone	48.00	1.0×10^{-6}	
Radon	222	6.0×10^{-18}	

[a]For this composition the average molecular weight assigned to air is 28.966. This composition of air is representative of dry air to altitudes of 75,000 - 100,000 feet.

Universal gas constant = 1545.35 ft lb/$^{\circ}$R-mol. On the basis of a pound of air the gas constant becomes:

$$R' = \frac{1545.35}{28.966} = 53.35 \text{ ft}/^{\circ}\text{R}$$

*"Manual of the ICAO Standard Atmosphere," Calculations by the NACA, NACA Report TN 3182, May 1954.

Working Charts for Airflow Characteristics

The charts in this section have been prepared within GE-ANPD in order to facilitate compressible-flow calculations. The basic source material is either Keenan and Kaye Gas Tables* information or other property data presented in the section "Physical Properties of Air."

The air dynamics chart permits interrelation of the following variables:

T' Total Temperature, ^{o}R
T Static Temperature, ^{o}R
P' Total Pressure, psf, psi
P Static Pressure, psf, psi
γ Ratio of Specific Heats
M Mach Number
G Mass Velocity, lb/sec-ft^2 lb/sec-in^2
(Consistent with pressure units)

The variables are presented in terms of the following relations:

$$P/P' = \left[1 + \left(\frac{\gamma - 1}{2}\right) M^2\right]^{\gamma/1-\gamma}$$

$$T/T' = \left[1 + \left(\frac{\gamma - 1}{2}\right) M^2\right]^{-1}$$

$$G/P' = M\sqrt{\frac{g\gamma}{TR}}\left(\frac{P}{P'}\right)$$

Use of Charts

The dynamics chart, Figure 4A, is basically a plot of M, P'/P, γM^2, and G/P' versus T'/T arranged so that graphical interrelation of ordinate functions is possible. Each term is plotted as a parameter of total temperature because of the temperature dependence of γ.

In order to utilize the chart it is necessary to know one ordinate value and the total temperature. The procedure is illustrated in the following sketch for the case of Mach number, M, and total temperature, T', known. Then G/P', and T'/T are calculated.

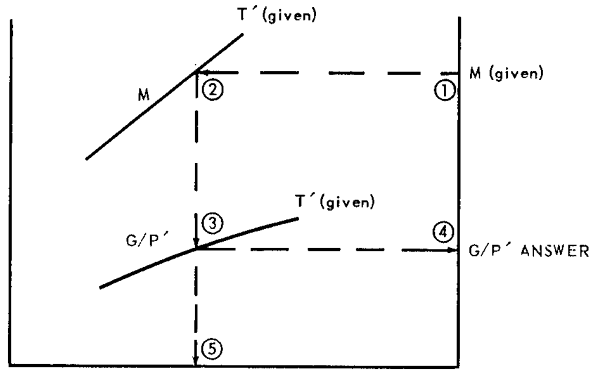
Other variables (P'/P and γM^2) are determined in a similar manner.

An adjunct solution that can be obtained is q/P where q = dynamic head in the same units as P, since q/P = (P'/P) - 1.0.

If static temperatures and pressures are known, rather than total values, various alternative methods of solution may be considered:

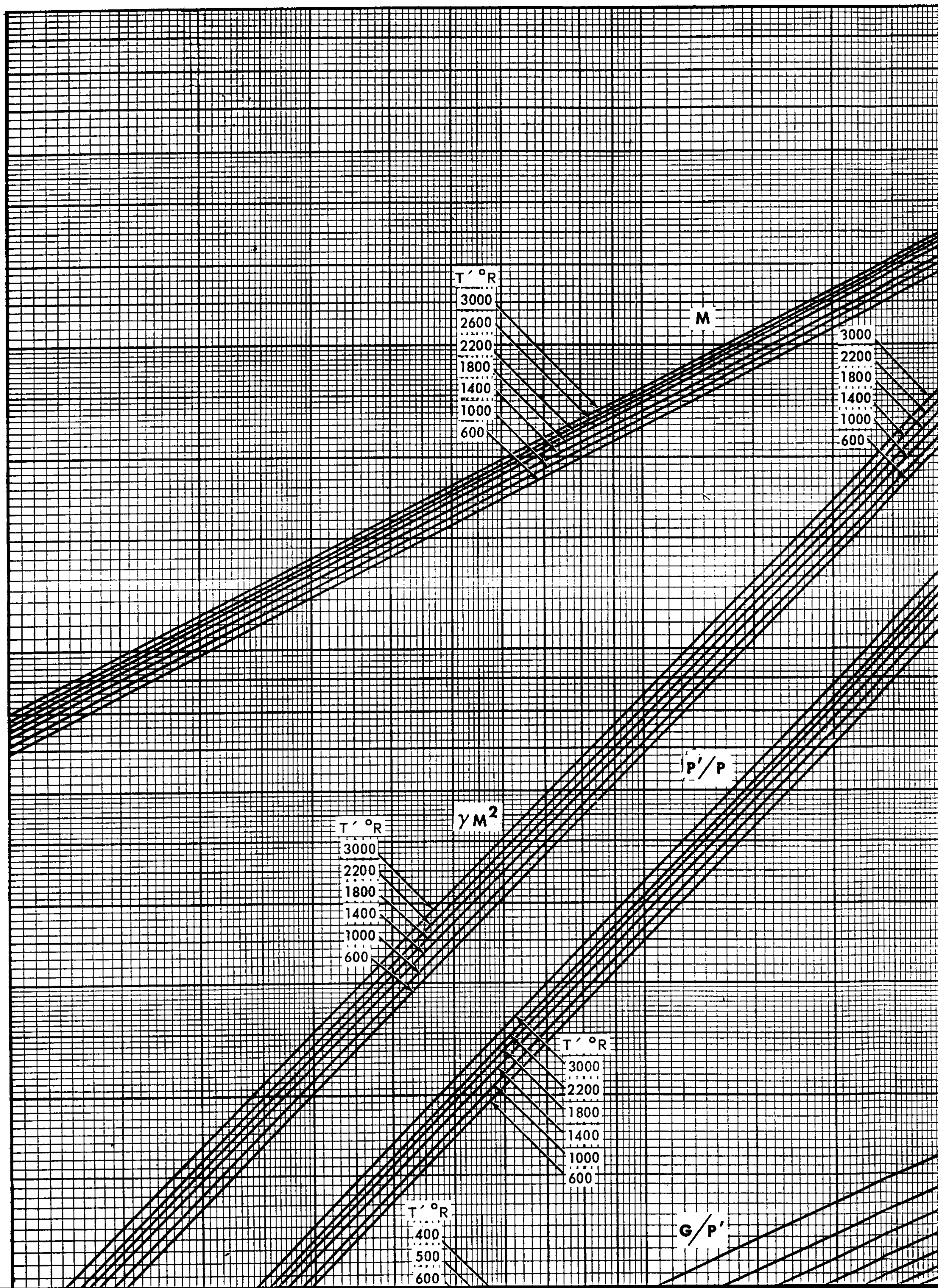
1. An auxiliary chart, Figure 4B, based on static pressure is included that can be used in conjunction with the basic chart for cases in which static pressure is initially known.

*J. H. Keenan, J. Kaye, *Gas Tables*, J. Wiley and Sons, 1948.

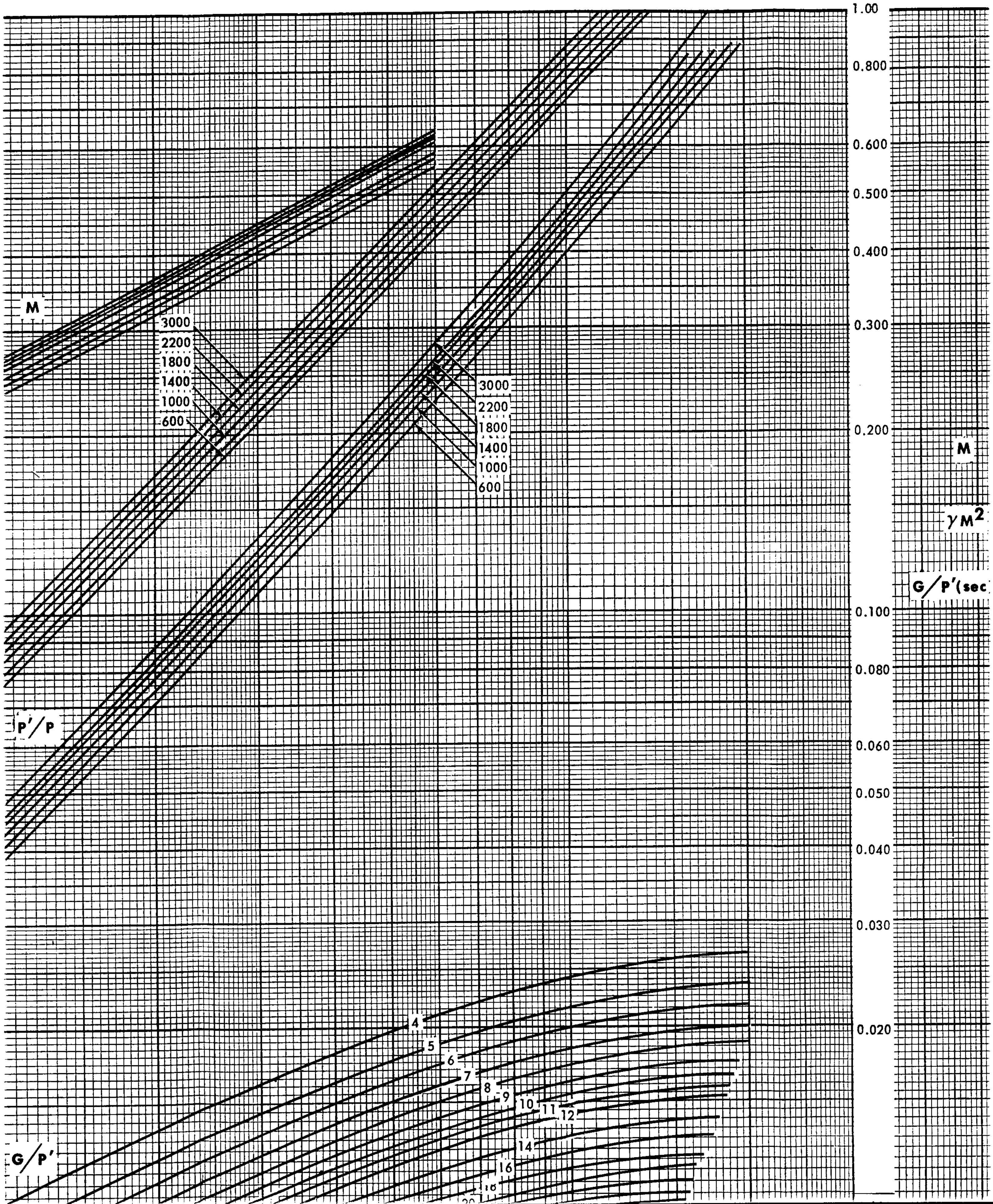


2. In general, T' and T may be used interchangeably for Mach numbers below 0.3. For other cases in which T is known, T' may be assumed and checked by iterative graphic calculation since T'/T is readily evaluated.

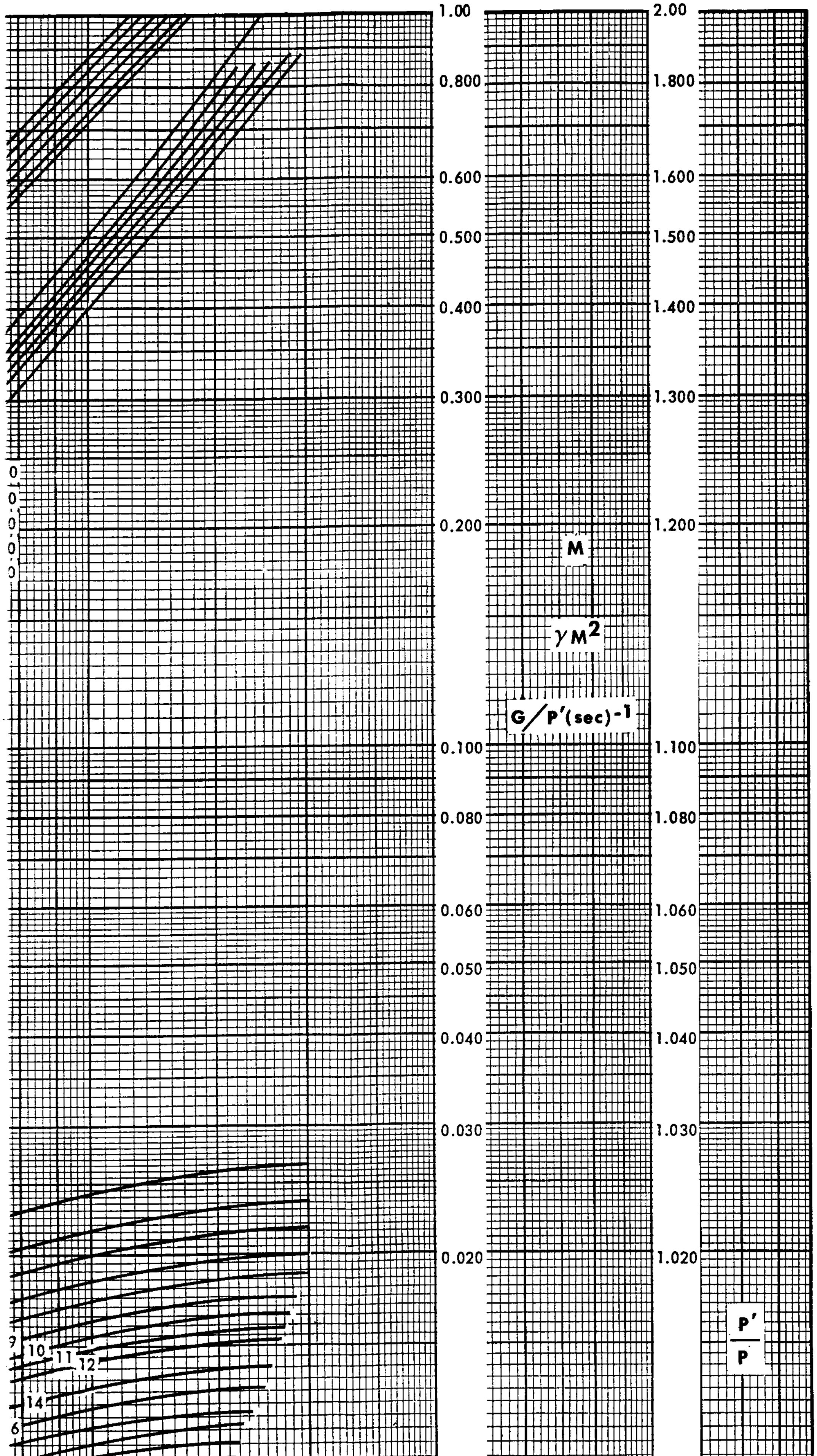
Alternate charts presented in Figures 5A and 5B or the exact formulae should be used if extreme accuracy is required.



T' °R
3000
2600
2200
1800
1400
1000
600
M
3000
2200
1800
1400
1000
600
P'/P
γM²
T' °R
3000
2200
1800
1400
1000
600
T' °R
3000
2200
1800
1400
1000
600
T' °R
400
500
600
G/P'



1.00
0.800
0.600
0.500
0.400
0.300
0.200
0.100
0.080
0.060
0.050
0.040
0.030
0.020
M
3000
2200
1800
1400
1000
600
3000
2200
1800
1400
1000
600
M
γM^2
G/P'(sec
P'/P
G/P'
4
5
6
7
8
9
10
11
12
14
16


1.00
0.800
0.600
0.500
0.400
0.300
0.200
0.100
0.080
0.060
0.050
0.040
0.030
0.020
2.00
1.800
1.600
1.500
1.400
1.300
1.200
1.100
1.080
1.060
1.050
1.040
1.030
1.020
M
γM^2
$G/P'(\text{sec})^{-1}$
$\frac{P'}{P}$
10
11
12
14

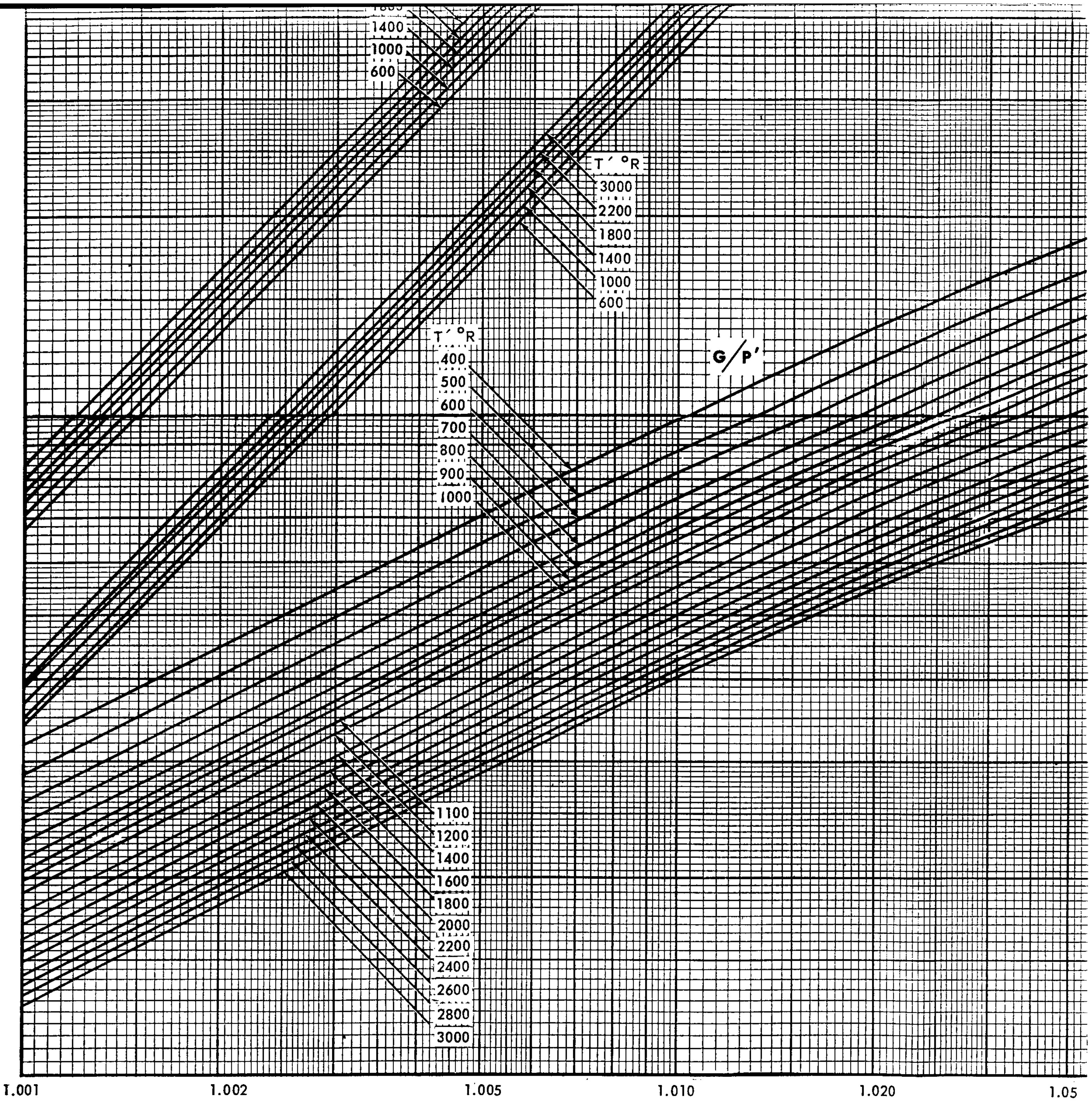
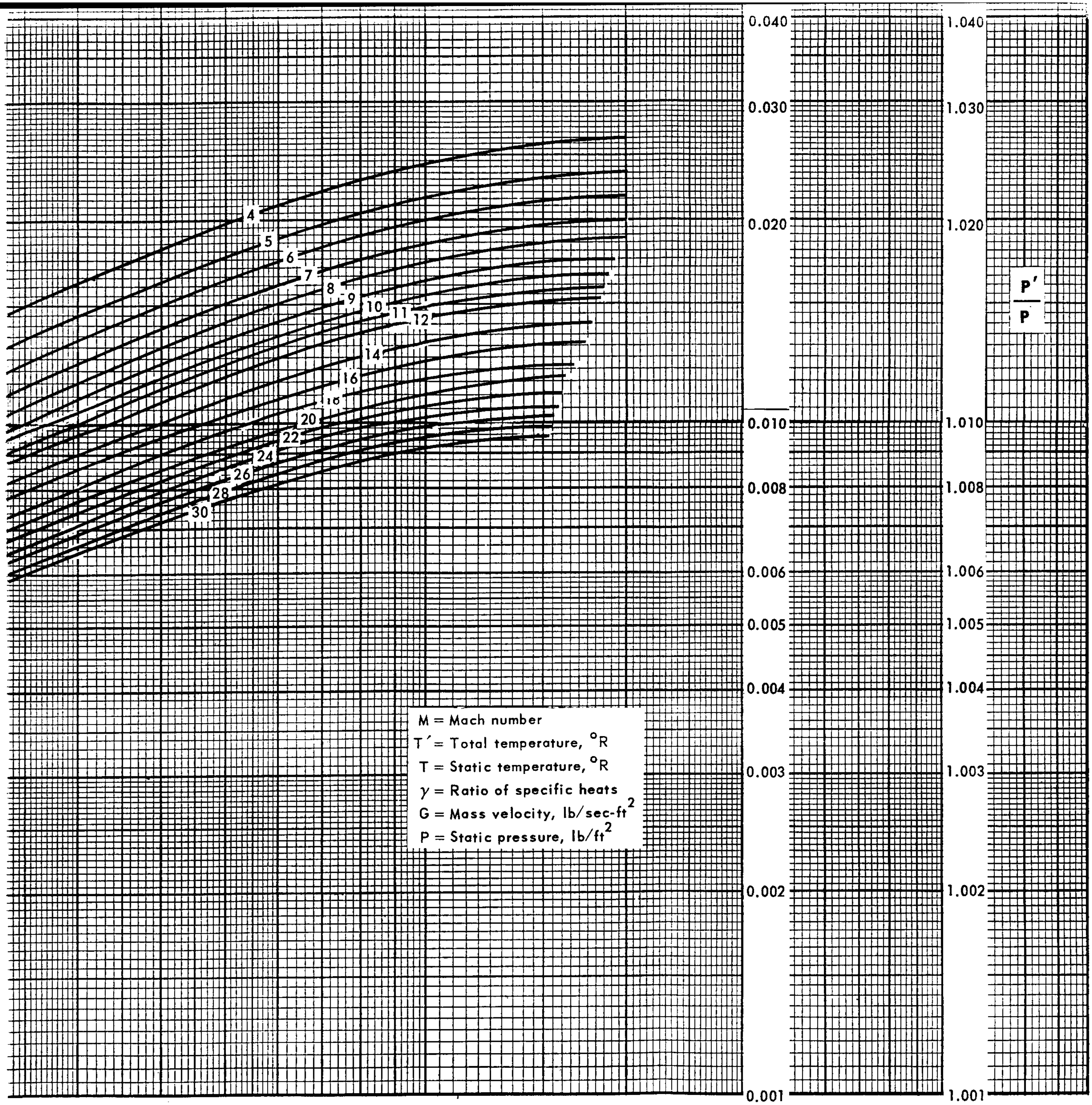


Fig. 4A – Air dynamics chart (reference data: Keenan



L TO STATIC TEMPERATURE (T′/T)

ference data: Keenan and Kaye "Air Tables," 1948)

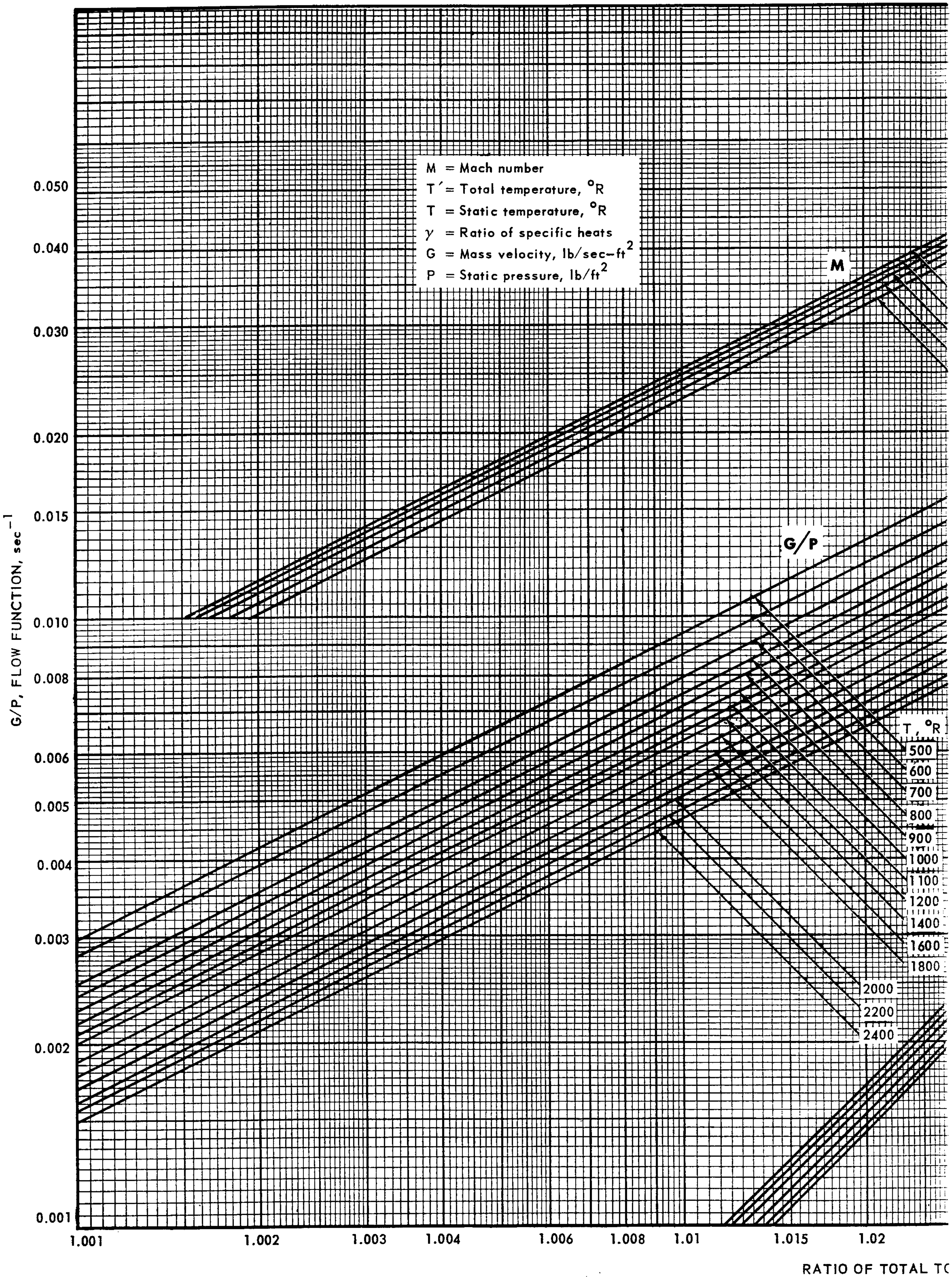

M = Mach number
T′ = Total temperature, °R
T = Static temperature, °R
γ = Ratio of specific heats
G = Mass velocity, lb/sec–ft²
P = Static pressure, lb/ft²
M
G/P
T, °R
500
600
700
800
900
1000
1100
1200
1400
1600
1800
2000
2200
2400
G/P, FLOW FUNCTION, sec⁻¹
0.050
0.040
0.030
0.020
0.015
0.010
0.008
0.006
0.005
0.004
0.003
0.002
0.001
1.001
1.002
1.003
1.004
1.006
1.008
1.01
1.015
1.02
RATIO OF TOTAL TC

Fig. 4B –

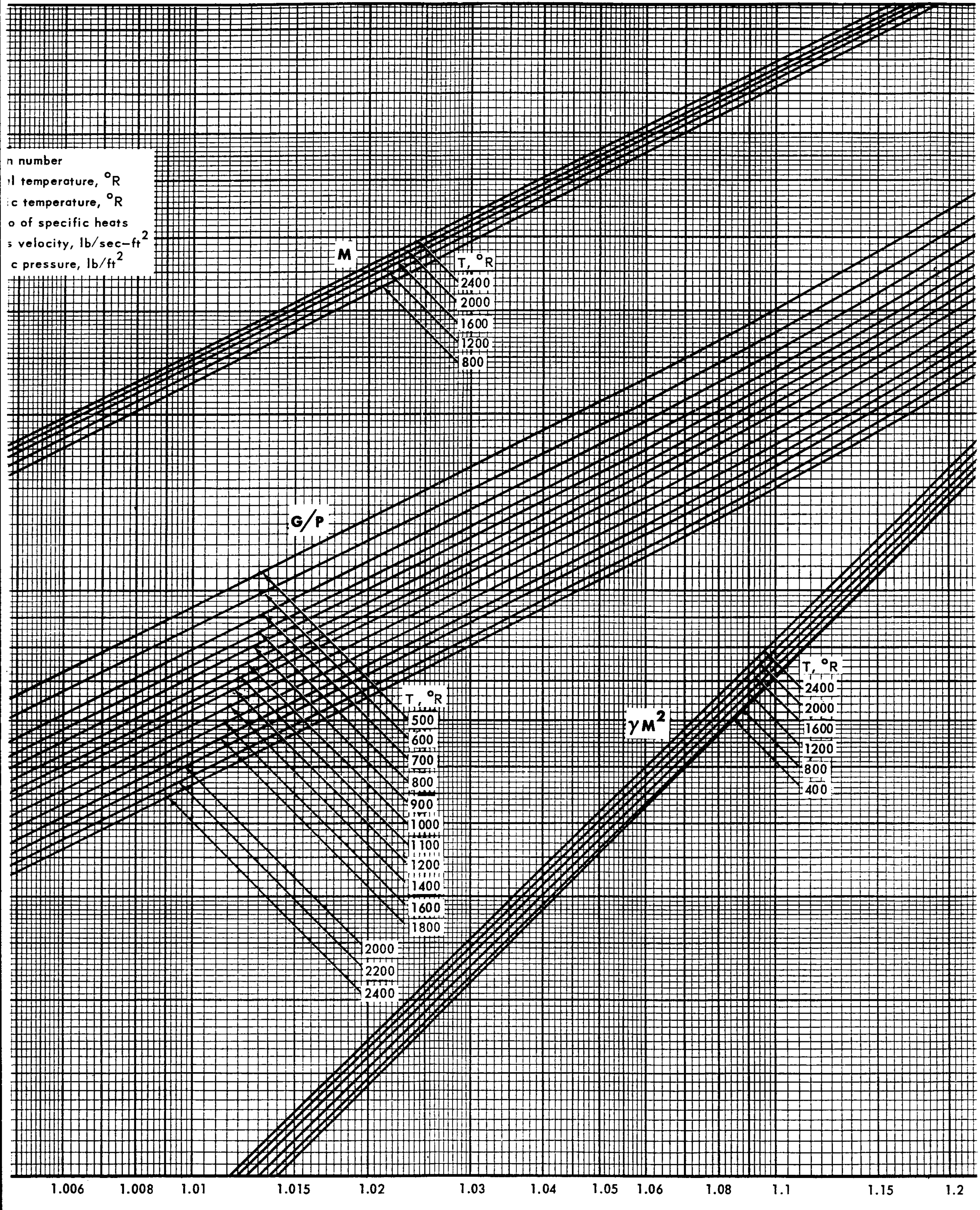
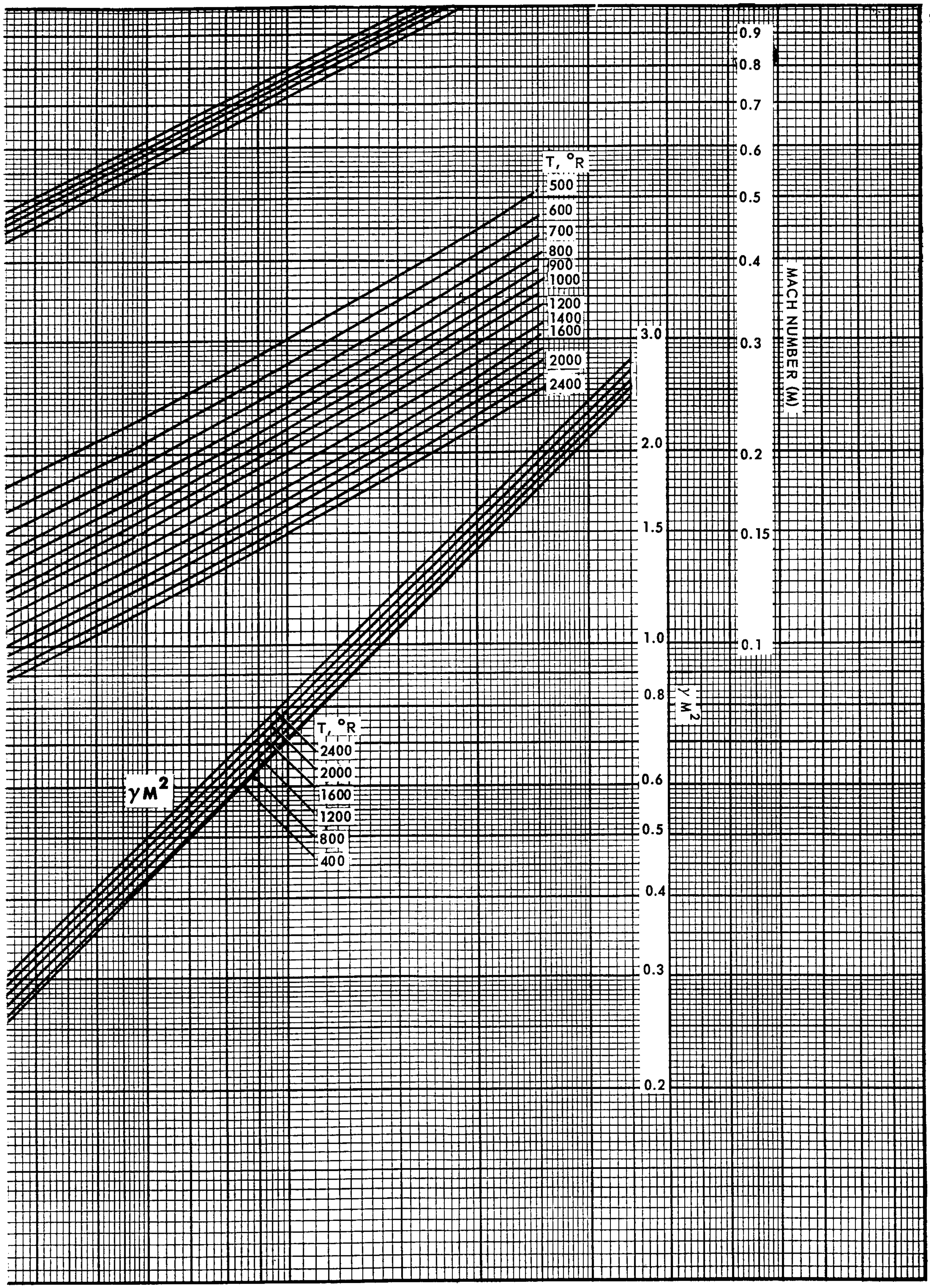
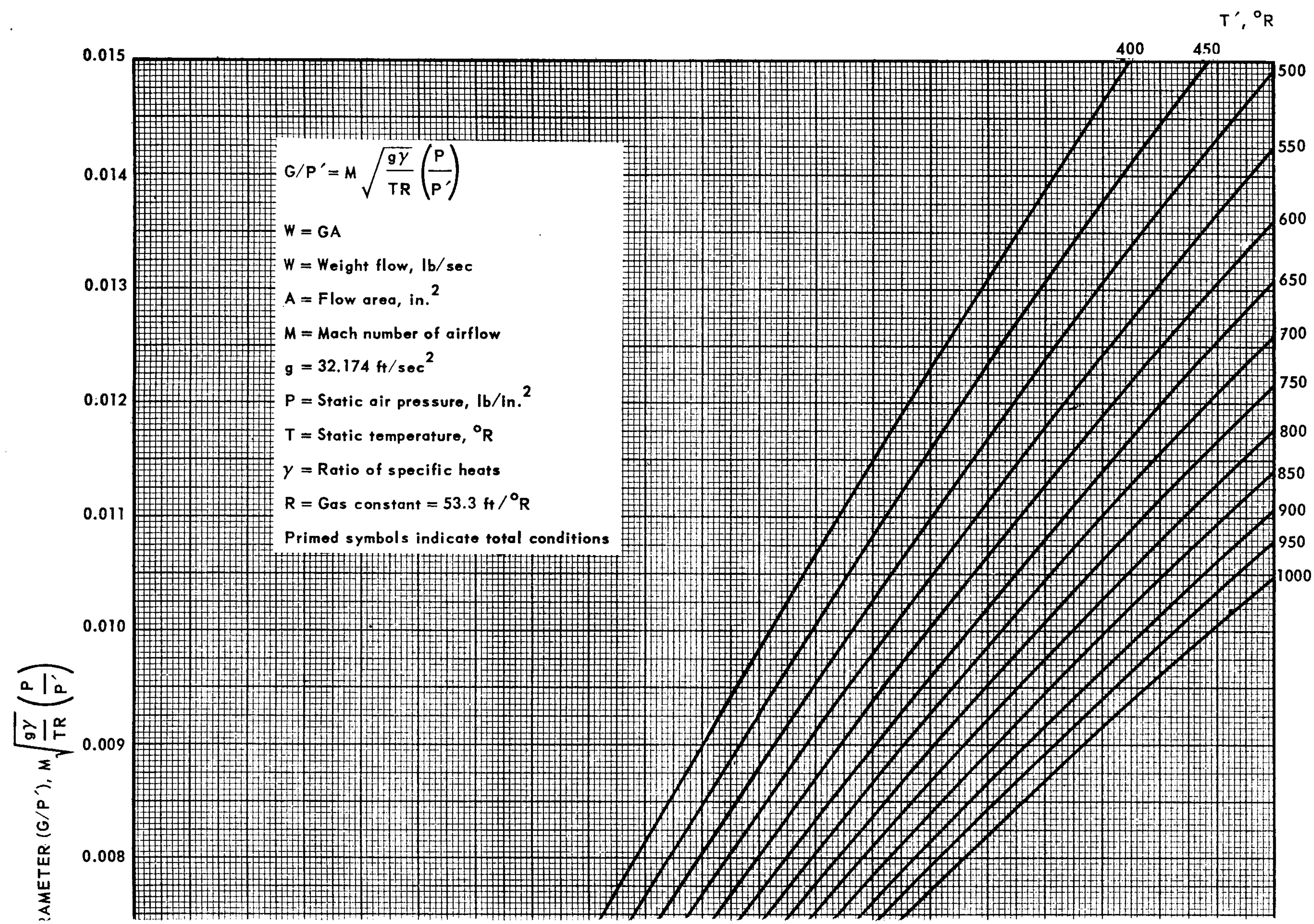


Fig. 4B – Air dynamics chart



TEMPERATURE (T′/T)

nics chart



T′, °R
400
450
500
550
600
650
700
750
800
850
900
950
1000
$G/P' = M \sqrt{\frac{g\gamma}{TR}} \left(\frac{P}{P'}\right)$
W = GA
W = Weight flow, lb/sec
A = Flow area, in.^{2}
M = Mach number of airflow
g = 32.174 ft/sec^2
P = Static air pressure, lb/in.^{2}
T = Static temperature, °R
γ = Ratio of specific heats
R = Gas constant = 53.3 ft/°R
Primed symbols indicate total conditions
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
AMETER (G/P′), $M\sqrt{\frac{g\gamma}{TR}}\left(\frac{P}{P'}\right)$

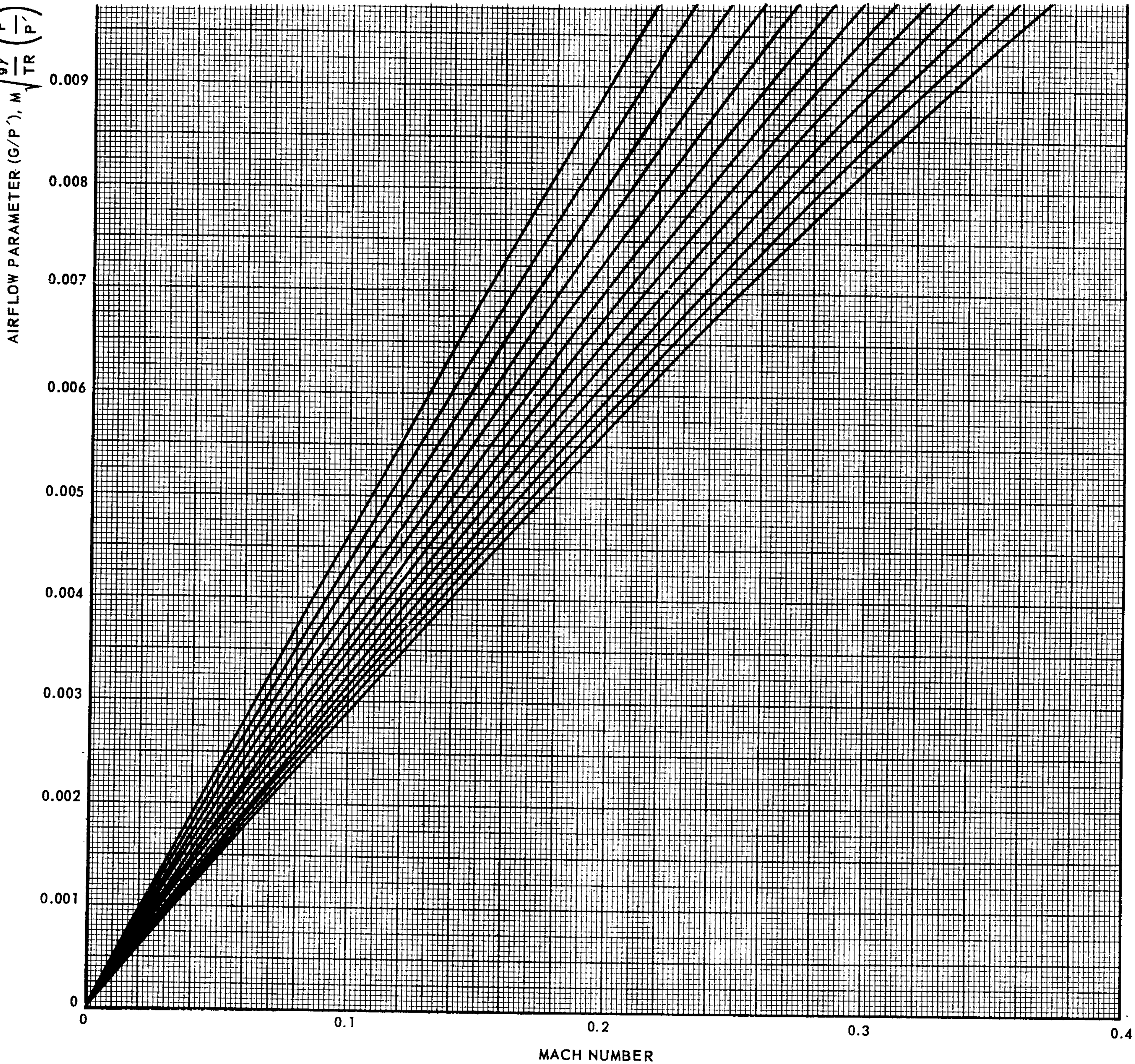


Fig. 5A – Airflow parameter G/P′ as a function of Mach number and air temperature

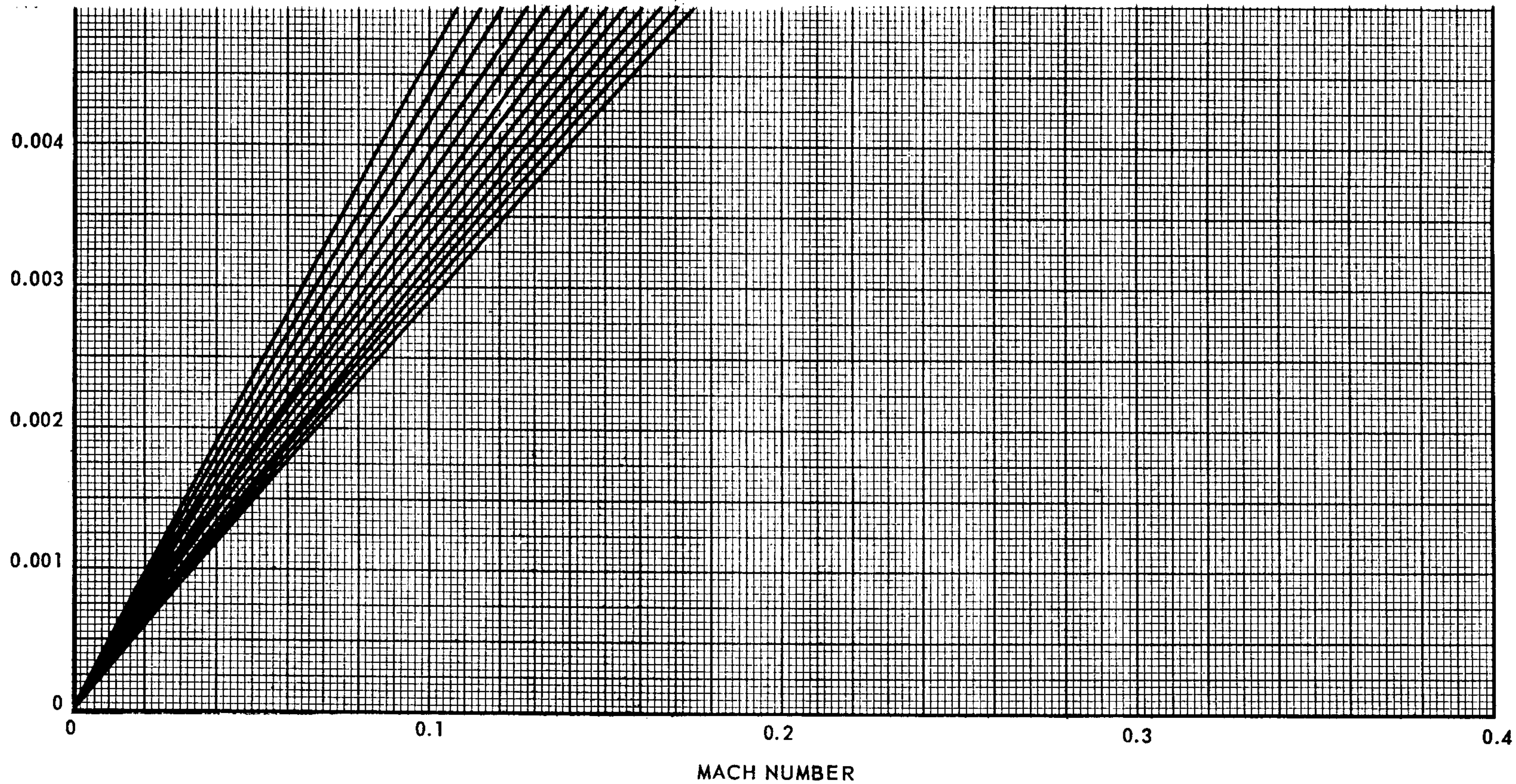
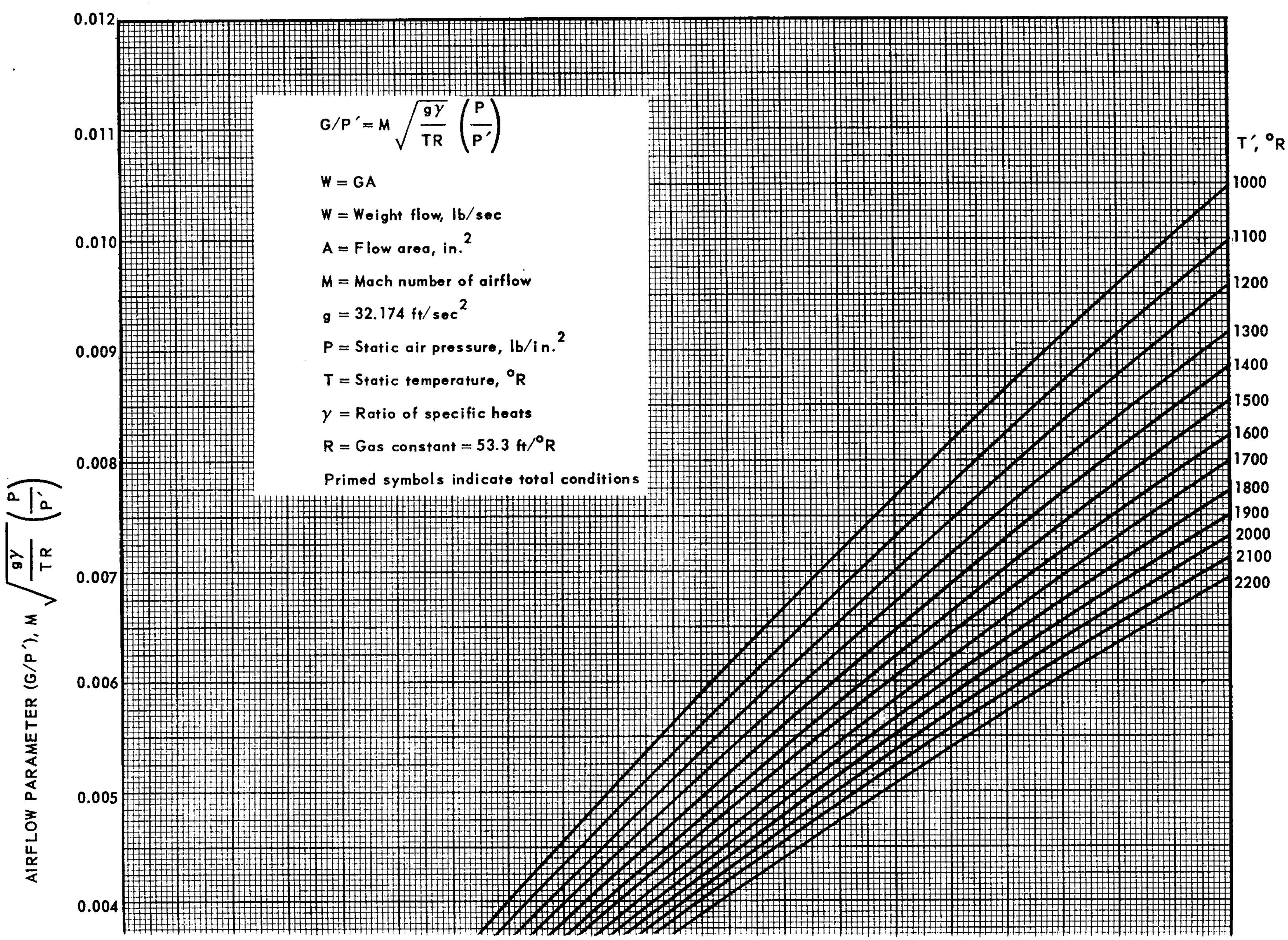


Fig. 5A – Airflow parameter G/P′ as a function of Mach number and air temperature from 400° to 1000°R



AIRFLOW PARAMETER (G/P′), M $\sqrt{\frac{g\gamma}{TR}}\left(\frac{P}{P'}\right)$
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
T′, °R
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
$G/P' = M\sqrt{\frac{g\gamma}{TR}}\left(\frac{P}{P'}\right)$
W = GA
W = Weight flow, lb/sec
A = Flow area, in.^{2}
M = Mach number of airflow
g = 32.174 ft/sec^2
P = Static air pressure, lb/in.^{2}
T = Static temperature, °R
γ = Ratio of specific heats
R = Gas constant = 53.3 ft/°R
Primed symbols indicate total conditions

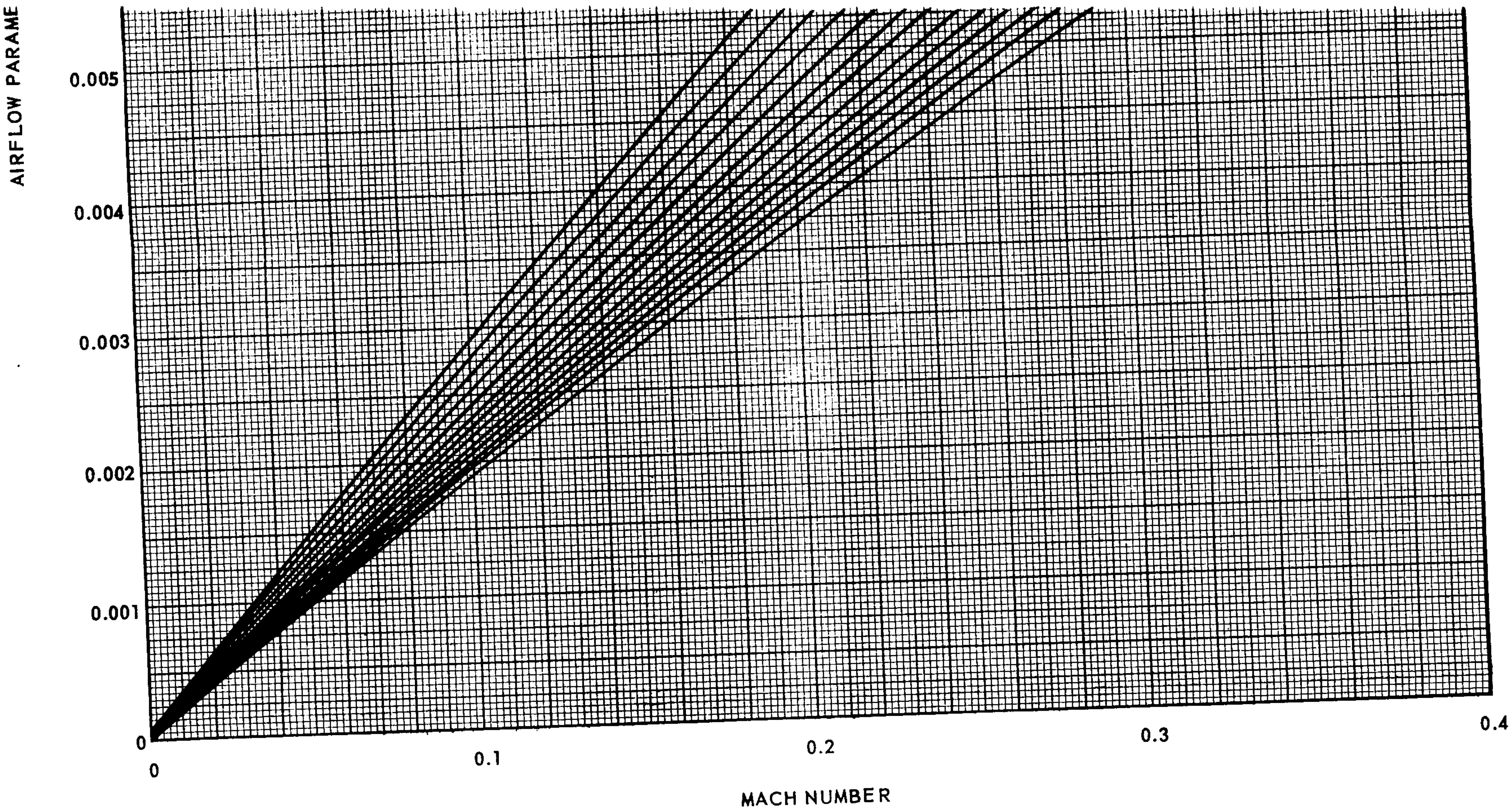


Fig. 5B – Airflow parameter G/P′ as a function of Mach number and air temperature from 1000° to 2200°R

Atmospheric Tables

This section contains various reference summaries of standard atmosphere tables (Tables 3 to 7) and charts (Figures 6 to 9) used in performance calculations.

The basic sources for these calculations are the following NACA reports:

Report TN 3182, Manual of the ICAO Standard Calculations by the NACA (May 1954).

Report 218, Standard Atmosphere Tables and Data (1925).

PROPERTIES OF THE STANDARD ATMOSPHERE.

Altitude, h ft	Pressure, p lb/ft^2	Pressure, p in. H_2O	Pressure, p in. Hg	Density, ρ slugs/ft^3	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temp., T °F abs.	Speed of sound, a mph	Coefficient of viscosity, μ slugs/ft sec	Kinematic viscosity, ν ft^2/sec
0	2116	407.1	29.92	0.002378	1.0000	1.0000	518.4	760.9	3.725 x 10^{-7}	1.566 x 10^{-4}
500	2078	399.8	29.38	.002343	.9855	1.007	516.6	759.6	3.716	1.586
1000	2041	392.6	28.86	.002309	.9710	1.015	514.8	758.3	3.705	1.604
1500	2004	385.5	28.33	.002275	.9568	1.022	513.0	757.0	3.695	1.624
2000	1968	378.5	27.82	.002242	.9428	1.030	511.2	755.7	3.685	1.644
2500	1932	371.6	27.31	.002209	.9288	1.038	509.5	754.3	3.674	1.663
3000	1896	364.8	26.81	.002176	.9151	1.045	507.7	753.0	3.664	1.684
3500	1862	358.2	26.32	.002144	.9015	1.053	505.9	751.7	3.654	1.704
4000	1828	351.6	25.84	.002112	.8881	1.061	504.1	750.4	3.644	1.725
4500	1794	345.1	25.36	.002080	.8748	1.069	502.4	749.1	3.633	1.747
5000	1760	338.7	24.89	.002049	.8616	1.077	500.6	747.7	3.623	1.768
5500	1728	332.4	24.43	.002018	.8487	1.085	498.8	746.4	3.612	1.790
6000	1696	326.2	23.98	.001988	.8358	1.094	497.0	745.1	3.602	1.812
6500	1664	320.1	23.53	.001957	.8232	1.102	495.2	743.7	3.592	1.835
7000	1633	314.1	23.09	.001928	.8106	1.111	493.4	742.3	3.581	1.857
7500	1602	308.2	22.65	.001898	.7982	1.119	491.7	741.0	3.571	1.881
8000	1572	302.4	22.22	.001869	.7859	1.128	489.9	739.7	3.561	1.905
8500	1542	296.6	21.80	.001840	.7738	1.137	488.1	738.3	3.550	1.929
9000	1512	291.0	21.38	.001812	.7619	1.146	486.3	737.0	3.540	1.954
9500	1483	285.4	20.98	.001784	.7501	1.155	484.5	735.6	3.529	1.978
10,000	1455	279.9	20.58	.001756	.7384	1.164	482.7	734.3	3.519	2.004
10,500	1427	274.5	20.18	.001728	.7269	1.173	481.0	732.9	3.508	2.030
11,000	1399	269.2	19.79	.001702	.7154	1.182	479.2	731.6	3.498	2.055
11,500	1372	264.0	19.40	.001675	.7042	1.192	477.4	730.2	3.487	2.082
12,000	1346	258.9	19.03	.001648	.6931	1.201	475.6	728.8	3.476	2.109
12,500	1319	253.8	18.65	.001622	.6821	1.211	473.8	727.5	3.466	2.137
13,000	1293	248.8	18.29	.001596	.6712	1.220	472.0	726.1	3.455	2.165
13,500	1268	243.9	17.93	.001570	.6605	1.230	470.3	724.7	3.445	2.194
14,000	1243	239.1	17.57	.001545	.6499	1.240	468.5	723.4	3.434	2.223
14,500	1218	234.4	17.22	.001520	.6394	1.250	466.7	722.0	3.423	2.252
15,000	1194	229.7	16.88	.001496	.6291	1.261	464.9	720.6	3.413	2.281
15,500	1170	225.1	16.54	.001472	.6189	1.271	463.1	719.2	3.402	2.311
16,000	1146	220.6	16.21	.001448	.6088	1.282	461.3	717.8	3.391	2.342
16,500	1123	216.1	15.89	.001424	.5988	1.292	459.6	716.4	3.380	2.374
17,000	1101	211.8	15.56	.001401	.5891	1.303	457.8	715.0	3.370	2.405
17,500	1078	207.5	15.25	.001378	.5793	1.314	456.0	713.6	3.359	2.438
18,000	1056	203.2	14.94	.001355	.5698	1.325	454.2	712.2	3.348	2.471
18,500	1035	199.1	14.63	.001333	.5603	1.336	452.4	710.8	3.337	2.503
19,000	1014	195.0	14.33	.001311	.5509	1.347	450.6	709.4	3.326	2.537
19,500	992.6	191.0	14.04	.001289	.5418	1.358	448.9	708.0	3.316	2.572
20,000	972.1	187.0	13.75	.001267	.5327	1.370	447.1	706.6	3.305	2.608
20,500	951.9	183.1	13.46	.001246	.5237	1.382	445.3	705.2	3.294	2.644
21,000	932.0	179.3	13.18	.001225	.5148	1.394	443.5	703.8	3.283	2.680
21,500	912.5	175.6	12.90	.001204	.5061	1.406	441.7	702.4	3.272	2.718
22,000	893.3	171.9	12.63	.001183	.4974	1.418	439.9	701.0	3.261	2.756
22,500	874.4	168.2	12.36	.001163	.4889	1.430	438.2	699.6	3.250	2.794
23,000	855.9	164.7	12.10	.001143	.4805	1.443	436.4	698.1	3.239	2.834
23,500	837.7	161.2	11.84	.001123	.4721	1.455	434.6	696.7	3.228	2.874
24,000	819.8	157.7	11.59	.001103	.4640	1.468	432.8	695.3	3.217	2.916
24,500	802.2	154.3	11.34	.001085	.4559	1.481	431.0	693.8	3.206	2.955
25,000	784.9	151.0	11.10	.001065	.4480	1.494	429.2	692.4	3.195	3.000
25,500	767.9	147.7	10.86	.001046	.4401	1.507	427.5	691.0	3.184	3.044
26,000	751.2	144.5	10.62	.001028	.4323	1.521	425.7	689.5	3.173	3.086
26,500	734.8	141.4	10.39	.001010	.4247	1.534	423.9	688.1	3.162	3.131
27,000	718.7	138.3	10.16	.000992	.4171	1.548	422.1	686.6	3.150	3.175
27,500	702.9	135.2	9.939	.000974	.4097	1.562	420.3	685.2	3.139	3.223
28,000	687.4	132.2	9.720	.000957	.4023	1.577	418.5	683.7	3.128	3.268

TABLE 3

PROPERTIES OF THE STANDARD ATMOSPHERE (Cont).

Altitude, h ft	Pressure, p lb/ft^2	Pressure, p in. H_2O	Pressure, p in. Hg	Density, ρ slugs/ft^3	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temp., T °F abs.	Speed of sound, a mph	Coefficient of viscosity, μ slugs/ft sec	Kinematic viscosity, ν ft^2/sec
28,500	672.1	129.3	9.504	0.000940	0.3951	1.591	416.8	682.3	3.117×10^{-7}	3.316×10^{-4}
29,000	657.1	126.4	9.293	.000922	.3879	1.606	415.0	680.8	3.106	3.369
29,500	642.4	123.6	9.085	.000906	.3809	1.620	413.2	679.3	3.094	3.415
30,000	628.0	120.8	8.880	.000889	.3740	1.635	411.4	677.9	3.083	3.468
30,500	613.8	118.0	8.680	.000873	.3671	1.650	409.6	676.4	3.072	3.519
31,000	599.9	115.4	8.483	.000857	.3603	1.666	407.8	674.9	3.060	3.570
31,500	586.3	112.8	8.290	.000842	.3537	1.682	406.1	673.4	3.049	3.621
32,000	572.9	110.2	8.101	.000826	.3472	1.697	404.3	672.0	3.038	3.678
32,500	559.7	107.6	7.915	.000810	.3406	1.713	402.5	670.5	3.026	3.736
33,000	546.8	105.2	7.732	.000795	.3343	1.730	400.7	669.0	3.015	3.792
33,500	534.1	102.8	7.554	.000780	.3280	1.746	399.0	667.5	3.004	3.851
34,000	521.7	100.4	7.377	.000765	.3218	1.763	397.2	666.0	2.992	3.911
34,500	509.5	98.03	7.205	.000750	.3158	1.779	395.4	664.5	2.981	3.975
35,000	497.6	95.75	7.036	.000736	.3098	1.797	393.6	663.0	2.969	4.034
35,332	489.8	94.24	6.926	.000727	.3058	1.808	392.4	662.0	2.962	4.073
35,500	485.8	93.51	6.873	.000721	.3034	1.816	392.4	662.0	2.962	4.105
36,000	474.4	91.31	6.711	.000705	.2963	1.837	392.4	662.0	2.962	4.204
36,500	463.2	89.15	6.552	.000688	.2893	1.859	392.4	662.0	2.962	4.306
37,000	452.2	87.04	6.397	.000672	.2824	1.881	392.4	662.0	2.962	4.410
37,500	441.6	85.00	6.247	.000656	.2758	1.904	392.4	662.0	2.962	4.516
38,000	431.1	82.97	6.098	.000640	.2692	1.927	392.4	662.0	2.962	4.625
38,500	421.0	81.01	5.954	.000625	.2629	1.950	392.4	662.0	2.962	4.737
39,000	411.0	79.10	5.813	.000610	.2567	1.974	392.4	662.0	2.962	4.852
39,500	401.3	77.23	5.676	.000596	.2506	1.998	392.4	662.0	2.962	4.969
40,000	391.9	75.44	5.544	.000582	.2448	2.021	392.4	662.0	2.962	5.089
40,500	382.6	73.64	5.412	.000568	.2390	2.045	392.4	662.0	2.962	5.212
41,000	373.6	71.89	5.284	.000555	.2333	2.070	392.4	662.0	2.962	5.338
41,500	364.8	70.18	5.158	.000542	.2278	2.095	392.4	662.0	2.962	5.467
42,000	356.2	68.56	5.038	.000529	.2225	2.120	392.4	662.0	2.962	5.599
42,500	347.8	66.93	4.919	.000516	.2172	2.146	392.4	662.0	2.962	5.735
43,000	339.6	65.34	4.802	.000504	.2120	2.172	392.4	662.0	2.962	5.873
43,500	331.5	63.79	4.688	.000492	.2070	2.198	392.4	662.0	2.962	6.015
44,000	323.7	62.29	4.578	.000480	.2021	2.224	392.4	662.0	2.962	6.161
44,500	316.1	60.82	4.470	.000469	.1974	2.251	392.4	662.0	2.962	6.310
45,000	308.6	59.40	4.365	.000458	.1927	2.278	392.4	662.0	2.962	6.462
45,500	301.3	58.01	4.263	.000448	.1882	2.305	392.4	662.0	2.962	6.618
46,000	294.2	56.63	4.162	.000437	.1838	2.333	392.4	662.0	2.962	6.778
46,500	287.3	55.28	4.063	.000427	.1794	2.361	392.4	662.0	2.962	6.942
47,000	280.5	53.98	3.967	.000417	.1752	2.389	392.4	662.0	2.962	7.110
47,500	273.9	52.72	3.875	.000407	.1711	2.418	392.4	662.0	2.962	7.282
48,000	267.4	51.46	3.782	.000397	.1670	2.447	392.4	662.0	2.962	7.459
48,500	261.1	50.24	3.692	.000388	.1630	2.477	392.4	662.0	2.962	7.640
49,000	255.0	49.06	3.605	.000379	.1592	2.506	392.4	662.0	2.962	7.824
49,500	248.9	47.92	3.522	.000370	.1555	2.536	392.4	662.0	2.962	8.012
50,000	243.1	46.78	3.438	.000361	.1518	2.567	392.4	662.0	2.962	8.206
50,500	237.3	45.67	3.357	.000352	.1482	2.598	392.4	662.0	2.962	8.404
51,000	231.7	44.60	3.276	.000344	.1447	2.629	392.4	662.0	2.962	8.607
51,500	226.3	43.54	3.200	.000336	.1413	2.660	392.4	662.0	2.962	8.815
52,000	220.9	42.52	3.124	.000328	.1379	2.692	392.4	662.0	2.962	9.028
52,500	215.7	41.51	3.051	.000320	.1347	2.725	392.4	662.0	2.962	9.246
53,000	210.6	40.53	2.979	.000313	.1315	2.758	392.4	662.0	2.962	9.470
53,500	205.6	39.57	2.908	.000305	.1284	2.791	392.4	662.0	2.962	9.699
54,000	200.8	38.64	2.840	.000298	.1254	2.824	392.4	662.0	2.962	9.933
54,500	196.1	37.73	2.773	.000291	.1224	2.858	392.4	662.0	2.962	10.17
55,000	191.4	36.84	2.707	.000284	.1195	2.893	392.4	662.0	2.962	10.42
55,500	186.9	35.97	2.644	.000278	.1167	2.927	392.4	662.0	2.962	10.67
56,000	182.5	35.12	2.581	.000271	.1140	2.962	392.4	662.0	2.962	10.93

PROPERTIES OF THE STANDARD ATMOSPHERE (Cont).

Altitude, h ft	Pressure, p lb/ft²	Pressure, p in. H_2O	Pressure, p in. Hg	Density, ρ slugs/ft³	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temp., T °F abs.	Speed of sound, a mph	Coefficient of viscosity, μ slugs/ft sec	Kinematic viscosity, ν ft²/sec
56,500	178.2	34.29	2.520	0.000264	0.1113	2.997	392.4	662.0	2.962×10^{-7}	11.19×10^{-4}
57,000	174.0	33.48	2.461	.000258	.1087	3.033	392.4	662.0	2.962	11.46
57,500	169.9	32.69	2.403	.000252	.1061	3.070	392.4	662.0	2.962	11.74
58,000	165.9	31.92	2.346	.000246	.1036	3.107	392.4	662.0	2.962	12.02
58,500	162.0	31.17	2.291	.000240	.1011	3.145	392.4	662.0	2.962	12.32
59,000	158.1	30.43	2.236	.000235	.09875	3.182	392.4	662.0	2.962	12.61
59,500	154.4	29.71	2.184	.000229	.09643	3.220	392.4	662.0	2.962	12.92
60,000	150.8	29.01	2.132	.000224	.09415	3.259	392.4	662.0	2.962	13.23
60,500	147.2	28.33	2.082	.000218	.09192	3.298	392.4	662.0	2.962	13.55
61,000	143.8	27.66	2.033	.000213	.08976	3.338	392.4	662.0	2.962	13.88
61,500	140.4	27.01	1.985	.000208	.08764	3.378	392.4	662.0	2.962	14.21
62,000	137.1	26.37	1.938	.000203	.08557	3.419	392.4	662.0	2.962	14.56
62,500	133.8	25.74	1.892	.000199	.08355	3.460	392.4	662.0	2.962	14.91
63,000	130.7	25.14	1.848	.000194	.08158	3.501	392.4	662.0	2.962	15.27
63,500	127.6	24.54	1.804	.000189	.07965	3.543	392.4	662.0	2.962	15.64
64,000	124.6	23.96	1.761	.000185	.07777	3.586	392.4	662.0	2.962	16.02
64,500	121.6	23.40	1.720	.000180	.07594	3.629	392.4	662.0	2.962	16.40
65,000	118.7	22.85	1.679	.000176	.07414	3.672	392.4	662.0	2.962	16.80

TABLE 4

PROPERTIES OF THE STANDARD ATMOSPHERE.

Altitude ft	Temp. °F	Temp. °F abs.	Temp. °F Mean abs.	Relative Temp. $\frac{T}{T_0}$	Relative Pressure $\frac{P}{P_0}$	Density Ratio $\sigma = \frac{\rho}{\rho_0}$	Pressure Abs P in. of Hg	Density slugs/ft³ ρ	Specific Gravity	Temp. °C
-4000	73.265	532.665	525.500	1.0275	1.1533	1.1225	34.51	0.002669	0.08588	22.925
-3400	71.125	530.525	524.439	1.0234	1.1293	1.1035	33.79	.002624	.08442	21.736
-3000	69.699	529.099	523.731	1.0206	1.1134	1.0909	33.31	.002594	.08346	20.944
-2400	67.559	526.959	522.669	1.0165	1.0899	1.0722	32.61	.002550	.08203	19.755
-2000	66.132	525.532	521.962	1.0138	1.0745	1.0599	32.15	.002520	.08109	18.962
-1400	63.992	523.392	520.895	1.0096	1.0516	1.0416	31.47	.002477	.07970	17.774
-1000	62.566	521.960	520.181	1.0069	1.0367	1.0296	31.02	.002448	.07878	16.981
-400	60.426	519.826	519.112	1.0027	1.0146	1.0118	30.36	.002406	.07741	15.792
0	59.000	518.400	518.400	1.0000	1.0000	1.0000	29.92	.002378	.07651	15.000
500	57.217	516.617	517.507	.9966	.9821	.9855	29.38	.002343	.07540	14.009
1000	55.434	514.834	516.615	.9931	.9644	.9710	28.86	.002309	.07430	13.019
1500	53.651	513.051	515.722	.9897	.9496	.9568	28.33	.002275	.07321	12.028
2000	51.868	511.268	514.830	.9862	.9298	.9428	27.82	.002242	.07213	11.038
2500	50.085	509.485	513.931	.9828	.9129	.9288	27.31	.002209	.07107	10.047
3000	48.301	507.701	513.033	.9794	.8962	.9151	26.81	.002176	.07001	9.056
3500	46.518	505.918	512.135	.9759	.8798	.9015	26.32	.002144	.06897	8.066
4000	44.735	504.135	511.237	.9725	.8636	.8881	25.84	.002112	.06794	7.075
4500	42.952	502.352	510.335	.9690	.8477	.8748	25.36	.002080	.06693	6.085
5000	41.169	500.569	509.434	.9656	.8320	.8616	24.89	.002049	.06592	5.094
5500	39.386	498.786	508.531	.9622	.8165	.8487	24.43	.002018	.06493	4.103

TABLE 4

PROPERTIES OF THE STANDARD ATMOSPHERE (Cont).

Altitude ft	Temp. °F	Temp. °F abs.	Temp. °F Mean abs.	Relative Temp. $\frac{T}{T_0}$	Relative Pressure $\frac{P}{P_0}$	Density Ratio $\sigma=\frac{\rho}{\rho_0}$	Pressure Abs P in. of Hg	Density slugs/ft³ ρ	Specific Gravity	Temp. °C
6000	37.603	497.003	507.629	0.9587	0.8013	0.8358	23.98	0.001988	0.06395	3.113
6500	35.820	495.220	506.723	.9553	.7863	.8232	23.53	.001957	.06298	2.122
7000	34.037	493.437	505.816	.9518	.7716	.8106	23.09	.001928	.06202	1.132
7500	32.254	491.654	504.910	.9484	.7571	.7982	22.65	.001898	.06107	0.141
8000	30.471	489.871	504.002	.9450	.7427	.7859	22.22	.001869	.06013	-0.850
8500	28.688	488.088	503.091	.9415	.7286	.7738	21.80	.001840	.05920	-1.840
9000	26.904	486.304	502.180	.9381	.7147	.7619	21.38	.001812	.05829	-2.831
9500	25.121	484.521	501.270	.9346	.7011	.7501	20.98	.001784	.05739	-3.281
10000	23.338	482.738	500.359	.9312	.6876	.7384	20.58	.001756	.05649	-4.812
10500	21.555	480.955	499.448	.9278	.6743	.7269	20.18	.001728	.05561	-5.803
11000	19.772	479.172	498.535	.9243	.6614	.7154	19.79	.001702	.05474	-6.793
11500	17.989	477.389	497.623	.9209	.6486	.7042	19.40	.001675	.05388	-7.784
12000	16.206	475.606	496.710	.9175	.6359	.6931	19.03	.001648	.05303	-8.774
12500	14.423	473.823	495.787	.9140	.6234	.6821	18.65	.001622	.05219	-9.765
13000	12.640	472.040	494.865	.9106	.6112	.6712	18.29	.001596	.05136	-10.756
13500	10.857	470.257	493.941	.9071	.5992	.6605	17.93	.001570	.05054	-11.746
14000	9.074	468.474	493.017	.9037	.5873	.6499	17.57	.001545	.04973	-12.737
14500	7.291	466.691	492.093	.9003	.5757	.6394	17.22	.001520	.04893	-13.727
15000	5.507	464.907	491.168	.8968	.5642	.6291	16.88	.001496	.04814	-14.718
15500	3.724	463.124	490.242	.8934	.5530	.6189	16.54	.001472	.04736	-15.511
16000	1.941	461.341	489.317	.8899	.5418	.6088	16.21	.001448	.04658	-16.699
16500	0.158	459.558	488.387	.8865	.5309	.5988	15.89	.001424	.04583	-17.690
17000	-1.625	457.775	487.459	.8831	.5202	.5891	15.56	.001401	.04507	-18.680
17500	-3.408	455.992	486.529	.8796	.5097	.5793	15.25	.001378	.04433	-19.671
18000	-5.191	454.209	485.598	.8762	.4992	.5698	14.94	.001355	.04359	-20.662
18500	-6.974	452.426	484.664	.8727	.4891	.5603	14.63	.001333	.04287	-21 652
19000	-8.757	450.643	483.729	.8693	.4790	.5509	14.33	.001311	.04216	-22.643
19500	-10.540	448.860	482.794	.8659	.4691	.5418	14.04	.001289	.04145	-23.633
20000	-12.323	447.077	481.859	.8624	.4594	.5327	13.75	.001267	.04075	-24.624
20500	-14.106	445.294	480.921	.8590	.4498	.5237	13.46	.001246	.04007	-25.615
21000	-15.890	444.510	479.980	.8555	.4405	.5148	13.18	.001225	.03938	-26.605
21500	-17.673	441.727	479.042	.8521	.4313	.5061	12.90	.001204	.03872	-27.596
22000	-19.456	439.944	478.100	.8487	.4222	.4974	12.63	.001183	.03806	-28.586
22500	-21.239	438.161	477.156	.8452	.4133	.4889	12.36	.001163	.03740	-29.577
23000	-23.022	436.378	476.210	.8418	.4045	.4805	12.10	.001143	.03676	-30.568
23500	-24.805	434.595	475.265	.8383	.3959	.4721	11.84	.001123	.03612	-31.558
24000	-26.588	432.812	474.320	.8349	.3874	.4640	11.59	.001103	.03550	-32.549
24500	-28.371	431.029	473.370	.8315	.3791	.4559	11.34	.001085	.03488	-33.539
25000	-30.154	429.246	472.420	.8280	.3790	.4480	11.10	.001065	.03427	-34.530
25500	-31.937	427.463	471.469	.8246	.3629	.4401	10.86	.001046	.03367	-35.521
26000	-33.720	425.680	470.518	.8211	.3550	.4323	10.62	.001028	.03308	-36.511
26500	-35.504	423.896	469.563	.8177	.3474	.4247	10.39	.001010	.03249	-37.502
27000	-37.287	422.113	468.607	.8143	.3397	.4171	10.16	.000992	.03192	-38.493
27500	-39.070	420.330	467.651	.8108	.3322	.4097	9.939	.000974	.03134	-39.483
28000	-40.853	418.547	466.695	.8074	.3248	.4023	9.720	.000957	.03078	-40.474

PROPERTIES OF THE STANDARD ATMOSPHERE (Cont).

Altitude ft	Temp. °F	Temp. °F abs.	Temp. °F Mean abs.	Relative Temp. $\frac{T}{T_0}$	Relative Pressure $\frac{P}{P_0}$	Density Ratio $\sigma = \frac{\rho}{\rho_0}$	Abs Pressure P in. of Hg	Density slugs/ft^3 ρ	Specific Gravity	Temp. °C
28500	-42.636	416.764	465.734	0.8039	0.3176	0.3951	9.504	0.000940	0.03023	-41.464
29000	-44.419	414.981	464.773	.8005	.3106	.3879	9.293	.000922	.02968	-42.455
29500	-46.202	413.198	463.811	.7971	.7971	.3809	9.085	.000906	.02914	-43.446
30000	-47.985	411.415	462.849	.7936	.2968	.3740	8.880	.000889	.02861	-44.436
30500	-49.768	409.632	461.882	.7902	.2900	.3671	8.680	.000873	.02809	-45.427
31000	-51.551	407.849	460.914	.7867	.2834	.3603	8.483	.000857	.02757	-46.417
31500	-53.334	406.066	459.947	.7833	.2770	.3537	8.290	.000842	.02706	-47.408
32000	-55.117	404.283	458.980	.7799	.2707	.3472	8.101	.000826	.02656	-48.399
33000	-58.684	400.716	457.034	.7730	.2583	.3343	7.732	.000795	.02558	-50.379
34000	-62.250	397.150	455.087	.7661	.2465	.3218	7.377	.000765	.02463	-52.361
35000	-65.816	393.584	453.132	.7592	.2352	.3098	7.036	.000736	.02369	-54.342
35332	-67.000	392.400	452.680	.7569	.2314	.3058	6.925	.000727	.02339	-55.000
36000	-67.000	392.400	451.198	.7569	.2242	.2962	6.708	.000704	.02265	-55.000
37000	-67.000	392.400	449.369	.7569	.2137	.2824	6.395	.000671	.02160	-55.000
38000	-67.000	392.400	447.648	.7569	.2037	.2692	6.096	.000640	.02059	-55.000
39000	-67.000	392.400	446.049	.7569	.1943	.2566	5.812	.000610	.01963	-55.000
40000	-67.000	392.400	444.537	.7569	.1852	.2447	5.541	.000582	.01872	-55.000
41000	-67.000	392.400	443.104	.7569	.1765	.2332	5.283	.000554	.01785	-55.000
42000	-67.000	392.400	441.742	.7569	.1683	.2224	5.036	.000529	.01701	-55.000
43000	-67.000	392.400	440.455	.7569	.1605	.2120	4.802	.000504	.01622	-55.000
44000	-67.000	392.400	439.232	.7569	.1530	.2021	4.578	.000481	.01546	-55.000
45000	-67.000	392.400	438.071	.7569	.1458	.1926	4.364	.000459	.01474	-55.000
46000	-67.000	392.400	436.964	.7569	.1391	.1837	4.160	.000437	.01405	-55.000
47000	-67.000	392.400	435.912	.7569	.1325	.1751	3.966	.000417	.01339	-55.000
48000	-67.000	392.400	434.906	.7569	.1264	.1669	3.781	.000397	.01277	-55.000
49000	-67.000	392.400	433.948	.7569	.1205	.1591	3.604	.000382	.01217	-55.000
50000	-67.000	392.400	433.030	.7569	.1149	.1517	3.436	.000361	.01161	-55.000
51000	-67.000	392.400	432.151	.7569	.1095	.1447	3.276	.000344	.01106	-55.000
52000	-67.000	392.400	431.312	.7569	.1044	.1380	3.123	.000328	.010550	-55.000
53000	-67.000	392.400	430.507	.7569	.09955	.1314	2.978	.000312	.010057	-55.000
54000	-67.000	392.400	429.734	.7569	.09491	.1253	2.839	.000298	.009591	-55.000
55000	-67.000	392.400	428.991	.7569	.09049	.1195	2.707	.000284	.009143	-55.000
56000	-67.000	392.400	428.279	.7569	.08626	.1140	2.581	.000271	.008718	-55.000
57000	-67.000	392.400	427.592	.7569	.08223	.1087	2.460	.000258	.008310	-55.000
58000	-67.000	392.400	426.933	.7569	.07839	.1035	2.346	.000246	.007922	-55.000
59000	-67.000	392.400	426.297	.7569	.07473	.09870	2.237	.000234	.007553	-55.000
60000	-67.000	392.400	425.685	.7569	.07125	.09413	2.132	.000224	.007201	-55.000
61000	-67.000	392.400	425.093	.7569	.06792	.08974	2.033	.000214	.006865	-55.000
62000	-67.000	392.400	424.522	.7569	.06476	.08555	1.938	.000203	.006546	-55.000
63000	-67.000	392.400	423.972	.7569	.06173	.08156	1.847	.000194	.006239	-55.000
64000	-67.000	392.400	423.439	.7569	.05886	.07775	1.761	.000185	.005949	-55.000
65000	-67.000	392.400	422.922	.7569	.05611	.07412	1.680	.000176	.005671	-55.000

TABLE 5

ICAO STANDARD ATMOSPHERE - INLET CONDITIONS

Altitude, ft	M_p	P_0, lb/in.^{2}	T_0, ^oR	P_2/P_0	P_2, lb/in.^{2}	δ_2	T_2, ^oR	θ_2	$\sqrt{\theta_2}$
0	0	14. 696	518. 67	1. 0000	14. 696	1. 0000	518. 67	1. 0000	1. 0000
	0. 2			1. 0282	15. 110	1. 0282	522. 81	1. 0080	1. 0040
	0. 4			1. 1167	16. 42	1. 1167	535. 30	1. 0321	1. 0159
	0. 6			1. 2757	18. 748	1. 2757	556. 05	1. 0721	1. 0354
	0. 8			1. 5248	22. 408	1. 5248	585. 10	1. 1281	1. 0621
	0. 9			1. 6916	24. 860	1. 6916	602. 69	1. 1620	1. 0780
	1. 0			1. 8930	27. 819	1. 8930	622. 32	1. 1998	1. 0954
	1. 2			2. 4037	35. 325	2. 4037	667. 79	1. 2875	1. 1347
	1. 5			3. 5441	52. 084	3. 5441	751. 28	1. 4485	1. 2035
5000	0. 04	12. 228	500. 86	1. 0011	12. 242	0. 83302	501. 02	0. 96597	0. 98284
	0. 1			1. 0071	12. 314	0. 83792	501. 86	0. 96759	0. 98366
	0. 2			1. 0282	12. 573	0. 85554	504. 87	0. 97339	0. 98661
	0. 4			1. 1167	13. 654	0. 92910	516. 93	0. 99665	0. 99834
	0. 6			1. 2759	15. 601	1. 0616	537. 00	1. 0354	1. 0175
	0. 8			1. 5247	18. 644	1. 2687	565. 05	1. 0894	1. 0438
	0. 9			1. 6918	20. 686	1. 4076	582. 08	1. 1222	1. 0594
	1. 0			1. 8930	23. 147	1. 5751	601. 07	1. 1589	1. 0765
	1. 2			2. 4039	29. 394	2. 0001	645. 02	1. 2436	1. 1152
	1. 5			3. 5434	43. 328	2. 9483	725. 72	1. 3992	1. 1829
10, 000	0. 1	10. 1065	483. 03	1. 0070	10. 177	0. 69251	483. 99	0. 93314	0. 96599
	0. 2			1. 0283	10. 393	0. 70720	486. 89	0. 93873	0. 96888
	0. 4			1. 1167	11. 286	0. 76798	498. 53	0. 96116	0. 98039
	0. 6			1. 2759	12. 894	0. 87741	517. 89	0. 99850	0. 99925
	0. 8			1. 5250	15. 412	1. 0487	544. 98	1. 0507	1. 0251
	0. 9			1. 7025	17. 207	1. 1708	561. 40	1. 0824	1. 0404
	1. 0			1. 8937	19. 138	1. 3023	579. 75	1. 1178	1. 0572
	1. 2			2. 4040	24. 296	1. 6533	622. 14	1. 1995	1. 0943
	1. 5			3. 5433	35. 810	2. 4367	700. 10	1. 3498	1. 1618
15, 000	0. 1	8. 2935	465. 20	1. 0070	8. 3516	0. 56829	466. 13	0. 89870	0. 94800
	0. 2			1. 0283	8. 5283	0. 58031	468. 92	0. 90408	0. 95083
	0. 4			1. 1167	9. 2614	0. 63020	480. 13	0. 92569	0. 96213
	0. 6			1. 2757	10. 580	0. 71996	498. 78	0. 96165	0. 98065
	0. 8			1. 5349	12. 730	0. 86623	524. 87	1. 0120	1. 0060
	0. 9			1. 6921	14. 033	0. 95491	540. 73	1. 0425	1. 0210
	1. 0			1. 8936	15. 705	1. 0686	558. 40	1. 0766	1. 0376
	1. 2			2. 4043	19. 940	1. 3568	599. 30	1. 1555	1. 0740
	1. 5			3. 5606	29. 530	2. 0094	674. 37	1. 3002	1. 1411
20, 000	0. 1	6. 7534	447. 37	1. 0070	6. 8007	0. 46276	448. 26	0. 86426	0. 92965
	0. 2			1. 0282	6. 9438	0. 47250	450. 95	0. 86943	0. 93243
	0. 4			1. 1162	7. 5381	0. 51294	461. 68	0. 89013	0. 94347
	0. 6			1. 2752	8. 6119	0. 58601	479. 62	0. 92471	0. 96163
	0. 8			1. 5346	10. 364	0. 70522	504. 71	0. 97310	0. 98646
	0. 9			1. 6913	11. 422	0. 77723	519. 97	1. 0025	1. 0012
	1. 0			1. 8941	12. 791	0. 87040	537. 01	1. 0354	1. 0175
	1. 2			2. 4036	16. 232	1. 1046	576. 38	1. 1113	1. 0542
	1. 5			3. 5416	23. 918	1. 6275	648. 68	1. 2507	1. 1183

Calculations include standard ram recovery equation

$$\eta_r = 1.0 - 0.1\,(M_p - 1)^{1.5}$$

$$\eta_r = 1.0 \text{ for } M_p < 1.0$$

TABLE 5

ICAO STANDARD ATMOSPHERE - INLET CONDITIONS (Cont.)

Altitude, ft	M_p	P_0, lb/in.^{2}	T_0, ^oR	P_2/P_0	P_2, lb/in.^{2}	δ_2	T_2, ^oR	θ_2	$\sqrt{\theta_2}$
25, 000	0. 2	5. 4535	429. 53	1. 0282	5. 6073	0. 38155	432. 97	0. 83478	0. 91366
	0. 4			1. 1164	6. 0883	0. 41428	443. 29	0. 85467	0. 92448
	0. 6			1. 2752	6. 9543	0. 47321	460. 50	0. 88785	0. 94226
	0. 8			1. 5240	8. 3111	0. 56554	484. 60	0. 93431	0. 96661
	0. 9			1. 6911	9. 2224	0. 62755	499. 25	0. 96255	0. 98110
	1. 0			1. 8930	10. 323	0. 70246	515. 61	0. 99410	0. 99705
	1. 2			2. 4035	13. 107	0. 89190	553. 45	1. 0671	1. 0330
	1. 5			3. 5399	19. 305	1. 3136	622. 91	1. 2010	1. 0968
	1. 7			4. 6466	25. 340	1. 7243	677. 72	1. 3067	1. 1431
30, 000	0. 3	4. 3641	411. 70	1. 0647	4. 6464	0. 31616	419. 16	0. 80814	0. 89897
	0. 5			1. 1864	5. 1776	0. 35231	432. 37	0. 83362	0. 91303
	0. 8			1. 5243	6. 6522	0. 45266	464. 53	0. 89562	0. 94637
	0. 9			1. 6913	7. 3810	0. 50225	478. 57	0. 92269	0. 96056
	1. 0			1. 8931	8. 2617	0. 56218	494. 25	0. 95293	0. 97618
	1. 2			2. 4039	10. 491	0. 71387	530. 57	1. 0229	1. 0114
	1. 5			3. 5414	15. 455	1. 0516	597. 22	1. 1515	1. 0731
	1. 7			4. 6475	20. 282	1. 3801	649. 79	1. 2528	1. 1193
	2. 0			7. 0461	30. 750	2. 0924	740. 65	1. 4280	1. 1950
35, 000	0. 9	3. 4580	393. 87	1. 6908	5. 8468	0. 39785	457. 80	0. 88265	0. 93950
	0. 95			1. 7867	6. 1784	0. 42042	465. 09	0. 89671	0. 94696
	1. 0			1. 8920	6. 5426	0. 44520	427. 77	0. 91151	0. 95473
	1. 2			2. 4022	8. 3068	0. 56525	507. 51	0. 97849	0. 98920
	1. 5			3. 5402	12. 242	0. 83302	571. 40	1. 1017	1. 0506
	1. 8			5. 3337	18. 444	1. 2550	649. 23	1. 2517	1. 1188
	2. 0			7. 0404	24. 346	1. 6566	708. 76	1. 3665	1. 1690
	2. 2			9. 2884	32. 119	2. 1856	774. 33	1. 4929	1. 2219
	2. 5			13. 962	48. 281	3. 2853	883. 52	1. 7035	1. 3052
36, 089	0. 9	3. 2825	389. 99	1. 6907	5. 5497	0. 37764	453. 29	0. 87395	0. 93486
	0. 95			1. 7865	5. 8642	0. 39903	460. 50	0. 88786	0. 94226
	1. 2			2. 4023	7. 8854	0. 53657	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	11. 621	0. 79073	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	17. 506	1. 1912	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	23. 105	1. 5722	701. 81	1. 3531	1. 1624
	2. 2			9. 2867	30. 483	2. 0743	766. 79	1. 4784	1. 2159
	2. 5			13. 966	45. 843	3. 1195	875. 01	1. 6870	1. 2989
	3. 0			26. 478	86. 914	5. 9142	1082. 5	2. 0871	1. 4447
40, 000	0. 95	2. 7200	389. 99	1. 7865	4. 8593	0. 33066	460. 50	0. 88786	0. 94226
	1. 2			2. 4023	6. 5342	0. 44463	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	9. 6292	0. 65523	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	14. 506	0. 98707	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	19. 146	1. 3028	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	25. 260	1. 7188	766. 89	1. 4784	1. 2159
	2. 5			13. 966	37. 988	2. 5849	875. 01	1. 6870	1. 2989
	3. 0			26. 478	72. 019	4. 9006	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	91. 373	6. 2176	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	127. 35	8. 6657	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	204. 88	13. 942	1588. 4	3. 0624	1. 7505

TABLE 5 (Cont.)
ICAO STANDARD ATMOSPHERE - INLET CONDITIONS

Altitude, ft	M_p	P_0, lb/in.^{2}	T_0, ^oR	P_2/P_0	P_2, lb/in.^{2}	δ_2	T_2, ^oR	θ_2	$\sqrt{\theta_2}$
45,000	0.95	2.1459	389.99	1.7865	3.8337	0.26087	460.50	0.88786	0.94226
	1.2			2.4023	5.1550	0.35078	502.51	0.96885	0.98430
	1.5			3.5402	7.5968	0.51694	565.78	1.0908	1.0444
	1.8			5.3330	11.444	0.77873	642.87	1.2395	1.1133
	2.0			7.0389	15.105	1.0278	701.81	1.3531	1.1632
	2.2			9.2867	19.928	1.3561	766.89	1.4784	1.2159
	2.5			13.966	29.970	2.0393	875.01	1.6870	1.2989
	3.0			26.478	56.819	3.8663	1082.5	2.0871	1.4447
	3.2			33.593	72.088	4.9053	1174.5	2.2644	1.5048
	3.5			46.820	100.47	6.8367	1321.3	2.5474	1.5961
	4.0			75.325	161.64	10.999	1588.4	3.0624	1.7505
50,000	0.95	1.6820	389.99	1.7865	3.0049	0.20448	460.50	0.88786	0.94226
	1.2			2.4023	4.0407	0.27495	502.51	0.96885	0.98430
	1.5			3.5402	5.9546	0.40519	565.78	1.0908	1.0444
	1.8			5.3330	8.9703	0.61039	642.87	1.2395	1.1133
	2.0			7.0389	11.840	0.80564	701.81	1.3531	1.1632
	2.2			9.2867	15.621	1.0629	766.89	1.4784	1.2159
	2.5			13.966	23.491	1.5985	875.01	1.6870	1.2989
	3.0			26.478	44.536	3.0305	1082.5	2.0871	1.4447
	3.2			33.593	56.504	3.8449	1174.5	2.2644	1.5048
	3.5			46.820	78.753	5.3588	1321.3	2.5474	1.5961
	4.0			75.325	126.70	8.6214	1588.4	3.0624	1.7505
55,000	0.95	1.3227	389.99	1.7865	2.3630	0.16079	460.50	0.88786	0.94226
	1.2			2.4023	3.1775	0.21622	502.51	0.96885	0.98430
	1.5			3.5402	4.6826	0.31863	565.78	1.0908	1.0444
	1.8			5.3330	7.0540	0.48000	642.87	1.2395	1.1133
	2.0			7.0389	9.3104	0.63354	701.81	1.3531	1.1632
	2.2			9.2867	12.284	0.83585	766.79	1.4784	1.2159
	2.5			13.966	18.473	1.2570	875.01	1.6870	1.2989
	3.0			26.478	35.022	2.3831	1082.5	2.0871	1.4447
	3.2			33.593	44.434	3.0236	1174.5	2.2644	1.5048
	3.5			46.820	61.929	4.2141	1321.3	2.5474	1.5961
	4.0			75.325	99.633	6.7797	1588.4	3.0624	1.7505
60,000	0.95	1.0402	389.99	1.7865	1.8582	0.12645	460.50	0.88786	0.94226
	1.2			2.4023	2.4987	0.17003	502.51	0.96885	0.98430
	1.5			3.5402	3.6823	0.25057	565.78	1.0908	1.0444
	1.8			5.3330	5.5471	0.37746	642.87	1.2395	1.1133
	2.0			7.0389	7.3215	0.49820	701.81	1.3531	1.1632
	2.2			9.2867	9.6596	0.65730	766.79	1.4784	1.2159
	2.5			13.966	14.527	0.98849	875.01	1.6870	1.2989
	3.0			26.478	27.541	1.8740	1082.5	2.0871	1.4447
	3.2			33.593	34.942	2.3777	1174.5	2.2644	1.5048
	3.5			46.820	48.700	3.3138	1321.3	2.5474	1.5961
	4.0			75.325	78.349	5.3314	1588.4	3.0624	1.7505

TABLE 5 (Cont.)
ICAO STANDARD ATMOSPHERE - INLET CONDITIONS

Altitude, ft	M_p	P_0, lb/in.^{2}	T_0, ^oR	P_2/P_0	P_2, lb/in.^{2}	δ_2	T_2, ^oR	θ_2	$\sqrt{\theta_2}$
65, 000	0. 95	0. 81796	389. 99	1. 7865	1. 4613	0. 099435	460. 50	0. 88786	0. 94226
	1. 2			2. 4023	1. 9649	0. 13371	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	2. 8957	0. 19704	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	4. 3622	0. 29683	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	5. 7575	0. 39178	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	7. 5961	0. 51689	766. 79	1. 4784	1. 2159
	2. 5			13. 966	11. 424	0. 77733	875. 01	1. 6870	1. 2989
	3. 0			26. 478	21. 658	1. 4737	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	27. 478	1. 8698	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	38. 297	2. 6060	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	61. 613	4. 1925	1588. 4	3. 0624	1. 7505
70, 000	0. 95	0. 64321	389. 99	1. 7865	1. 1491	0. 078192	460. 50	0. 88786	0. 94226
	1. 2			2. 4023	1. 5452	0. 10514	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	2. 2771	0. 15495	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	3. 4032	0. 23341	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	4. 5275	0. 30808	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	5. 9733	0. 40646	766. 79	1. 4784	1. 2159
	2. 5			13. 966	8. 9831	0. 61126	875. 01	1. 6870	1. 2989
	3. 0			26. 478	17. 031	1. 1589	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	21. 607	1. 4703	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	30. 115	2. 0492	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	48. 450	3. 2968	1588. 4	3. 0624	1. 7505
75, 000	0. 95	0. 50582	389. 99	1. 7865	0. 90365	0. 061490	460. 50	0. 88786	0. 94226
	1. 2			2. 4023	1. 2151	0. 082685	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	1. 7907	0. 12185	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	2. 6975	0. 18356	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	3. 5604	0. 24227	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	4. 6974	0. 31964	766. 79	1. 4784	1. 2159
	2. 5			13. 966	7. 0643	0. 48070	875. 01	1. 6870	1. 2989
	3. 0			26. 478	13. 393	0. 91135	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	16. 992	1. 1562	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	23. 682	1. 6115	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	38. 101	2. 5926	1588. 4	3. 0624	1. 7505
80, 000	0. 95	0. 39777	389. 99	1. 7865	0. 71062	0. 048355	460. 50	0. 88786	0. 94226
	1. 2			2. 4023	0. 95556	0. 065022	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	1. 4082	0. 095822	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	2. 1213	0. 14435	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	2. 7999	0. 19052	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	3. 6940	0. 25136	766. 79	1. 4784	1. 2159
	2. 5			13. 966	5. 5553	0. 37801	875. 21	1. 6870	1. 2989
	3. 0			26. 478	10. 532	0. 71667	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	13. 362	0. 90925	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	18. 624	1. 2673	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	29. 962	2. 0388	1588. 4	3. 0624	1. 7505

TABLE 5 (Cont.)
ICAO STANDARD ATMOSPHERE - INLET CONDITIONS

Altitude, ft	M_p	P_0, lb/in.^{2}	T_0, ^oR	P_2/P_0	P_2, lb/in.^{2}	δ_2	T_2, ^oR	θ_2	$\sqrt{\theta_2}$
85, 000	1. 0	0. 31279	389. 99	1. 8918	0. 59174	0. 040265	468. 108	0. 90252	0. 95001
	1. 2			2. 4023	0. 75142	0. 051131	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	1. 1073	0. 075350	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	1. 6681	0. 11351	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	2. 2017	0. 14982	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	2. 9048	0. 19766	766. 79	1. 4784	1. 2159
	2. 5			13. 966	4. 3684	0. 29725	875. 01	1. 6870	1. 2989
	3. 0			26. 478	8. 2821	0. 57356	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	10. 508	0. 71500	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	14. 645	0. 99652	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	23. 561	1. 6032	1588. 4	3. 0624	1. 7505
90, 000	1. 0	0. 24594	389. 99	1. 8918	0. 46527	0. 031660	468. 108	0. 90252	0. 95001
	1. 2			2. 4023	0. 59082	0. 040203	502. 51	0. 96885	0. 98430
	1. 5			3. 5402	0. 87068	0. 059246	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	1. 3116	0. 089249	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	1. 7311	0. 11780	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	2. 2840	0. 15542	766. 79	1. 4784	1. 2159
	2. 5			13. 966	3. 4348	0. 23372	875. 01	1. 6870	1. 2989
	3. 0			26. 478	6. 5120	0. 44312	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	8. 2619	0. 56219	1174. 5	2. 2644	1. 5048
	3. 5			46 820	11. 515	0. 78355	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	18. 525	1. 2606	1588. 4	3. 0624	1. 7505
95, 000	1. 5	0. 19339	389. 99	3. 5402	0. 68464	0. 046587	565. 78	1. 0908	1. 0444
	1. 8			5. 3330	1. 0313	0. 070179	642. 87	1. 2395	1. 1133
	2. 0			7. 0389	1. 3613	0. 092628	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	1. 7960	0. 12221	766. 79	1. 4784	1. 2159
	2. 5			13. 966	2. 7009	0. 18378	875. 01	1. 6870	1. 2989
	3. 0			26. 478	5. 1206	0. 34844	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	6. 4966	0. 44207	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	9. 0545	0. 61613	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	14. 567	0. 99124	1588. 4	3. 0624	1. 7505
100, 000	2. 0	0. 15211	389. 99	7. 0389	1. 0707	0. 072856	701. 81	1. 3531	1. 1632
	2. 2			9. 2867	1. 4126	0. 096122	766. 79	1. 4784	1. 2159
	2. 5			13. 966	2. 1244	0. 14456	875. 01	1. 6870	1. 2989
	3. 0			26. 478	4. 0276	0. 27406	1082. 5	2. 0871	1. 4447
	3. 2			33. 593	5. 1098	0. 34770	1174. 5	2. 2644	1. 5048
	3. 5			46. 820	7. 1218	0. 48461	1321. 3	2. 5474	1. 5961
	4. 0			75. 325	11. 458	0. 77965	1588. 4	3. 0624	1. 7505

M_p Flight mach number

P Total pressure, psia

T Total temperature, ^oR

δ_2 $P_2/14.696$

δ_2 $T_2/518.67$

Subscripts

0 Ambient conditions

2 Compressor inlet after ram recovery

Source: Flight Propulsion Division
General Electric Company

TABLE 6

RAM PRESSURE RATIOS (FOR 100% RAM EFFICIENCY) AND TOTAL TEMPERATURE AT NACA STANDARD ALTITUDES.

V = True Air Speed (ft per sec)
p_s = Static Pressure
p_t = Impact Pressure
T_t = Impact Temperature (°R)
T_s = Static Temperature (°R)

k = 1.4
R = 53.5

$$\left(\frac{p_t}{p_s}\right)^{\frac{k-1}{k}} - 1 = \left(\frac{k-1}{kRT_s}\right)\frac{V^2}{2g} \qquad T_t = T_s + \left(\frac{k-1}{kR}\right)\frac{V^2}{2g}$$

True Knots	Air Speed Ft/Sec		14.696*	12.227*	10.105*	8.292*	6.751*	5.451*	4.362*	3.455*	3.401*
0	0	P_t/P_s =	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
		T_t =	518.4	500.6	482.7	464.9	447.1	429.2	411.4	393.6	392.4
50	84.1		1.0037	1.00416	1.00435	1.0045	1.0047	1.00483	1.00497	1.0053	1.0053
			518.9	501.1	483.4	465.6	447.6	429.9	411.9	394.1	392.9
100	169.3		1.0161	1.01671	1.01735	1.0180	1.0187	1.0195	1.0204	1.0213	1.0214
			520.8	503.0	485.1	467.3	449.5	431.6	413.8	396.0	394.8
150	253.3		1.03565	1.03769	1.03929	1.04085	1.0423	1.04427	1.04621	1.04835	1.0485
			523.7	505.9	488.1	470.2	452.4	434.6	416.7	398.9	397.7
200	337.4		1.0657	1.0680	1.0706	1.0754	1.0764	1.07964	1.0833	1.0871	1.0874
			527.9	510.0	492.2	474.4	456.5	438.8	420.9	403.	401.9
250	422.6		1.1039	1.1077	1.1119	1.1164	1.1213	1.12649	1.1322	1.1384	1.13874
			533.3	515.4	497.6	479.8	462.0	444.1	426.3	408.5	407.3
300	506.7		1.1519	1.1577	1.16405	1.1705	1.1778	1.1855	1.1940	1.2032	1.2040
			539.8	521.9	504.0	486.3	468.5	450.7	432.8	415.0	413.8
350	590.8		1.2109	1.2188	1.2278	1.2371	1.2470	1.2582	1.2701	1.2839	1.2841
			547.4	529.6	511.9	493.9	476.1	458.4	440.4	422.6	421.4
400	676.0		1.282	1.2941	1.30399	1.3169	1.3308	1.3459	1.3640	1.3810	1.3815
			556.3	538.5	520.8	503.0	485.0	467.3	449.5	431.5	430.3
450	760.0		1.3640	1.3789	1.3948	1.4119	1.4301	1.4505	1.4726	1.4975	1.4995
			566.4	548.6	530.8	512.9	495.1	477.3	459.5	441.6	440.4
500	844.1		1.4621	1.4810	1.5013	1.5233	1.5475	1.5739	1.6034	1.6358	1.6372
			577.7	560.0	542.1	524.2	506.4	488.6	470.8	452.9	451.7
550	929.3		1.5759	1.5995	1.6259	1.6504	1.6842	1.7190	1.7578	1.8040	1.7950
			590.1	572.3	554.6	536.6	518.9	501.1	483.3	465.3	464.1
600	1013.4		1.7052	1.7359	1.7696	1.8065	1.8450	1.8890	1.9360	1.9905	1.9950
			603.8	586.0	568.2	550.4	532.5	514.7	496.8	479.0	477.8
650	1097.4		1.8585	1.8959	1.9371	1.9825	2.0190	2.0850	2.1478	2.2150	2.2198
			618.7	600.9	583.1	565.2	547.4	529.6	511.7	493.9	492.7
700	1181.5		2.0320	2.0780	2.1305	2.195	2.2479	2.3160	2.3937	2.4751	2.4830
			634.7	616.9	599.0	581.2	563.4	545.5	527.7	509.9	508.7
750	1266.7		2.2312	2.2900	2.3301	2.4226	2.4975	2.5849	2.6765	2.7810	2.7900
			652.0	634.0	616.2	598.4	580.7	562.8	544.9	527.2	525.9
800	1351.9		2.455	2.5280	2.6085	2 6925	2.7883	2.8900	3.0050	3.1720	3.3150
			670.3	653.8	634.7	616.8	599.0	581.2	563.4	545.5	543.9
Altitude			Sea Level	5,000	10,000	15,000	20,000	25,000	30,000	35,000	35,332

*Standard Atmosphere in lb sq in.

TABLE 7

DENSITY OF AIR

$$\rho = \frac{144\,P}{RT}$$ ρ=lbs/ft³ R=53.3 gas constant of air

P=psia T=Absolute temp. °R

°F	psia / R	1	2	3	4	5	6	7	8	9	10	11	12	13	14.7	20	25	30	35	40	45	50
-65	395	.0068	.0136	.0204	.0274	.0342	.0408	.0476	.0544	.0612	.0684	.0752	.0820	.0888	.1005	.1368	.1710	.2052	.2392	.2736	.3080	.3420
-40	420	.0064	.0128	.0192	.0257	.0322	.0384	0448	.0512	.0576	.0643	.0707	.0771	.0835	.0945	.1286	.1608	.1929	.2250	.2572	.2890	.3215
-20	440	.0061	.0122	.0183	.0244	.0307	.0366	.0427	.0488	.0549	.0614	.0675	.0736	.0798	.0903	.1228	.1532	.1832	.2145	.2456	.2760	.3070
-10	450	.0060	.0120	.0180	.0240	.0300	.0360	.0420	.0480	.0540	.0600	.0660	.0720	.0780	.0882	.1200	.1500	.1800	.2100	.2400	.2700	.3000
0	460	.0058	.0116	.0176	0235	.0294	.0348	.0406	.0464	.0522	.0587	.0645	.0705	.0763	.0863	.1174	.1468	.1761	.2055	.2348	.2642	.2935
10	470	.0057	.0114	.0173	.0230	.0288	.0342	.0399	.0456	.0513	.0575	.0633	.0690	.0747	.0845	.1150	.1438	.1725	.2012	.2300	.2590	.2875
20	480	.0056	.0112	.0169	.0225	.0282	.0336	0392	.0448	.0504	.0563	.0620	.0676	.0732	.0827	.1126	.1408	.1689	.1971	.2252	.2540	.2815
30	490	.0055	.0110	.0165	.0220	.0276	.0330	.0385	.0440	.0495	.0551	.0606	.0662	.0716	.0810	.1102	.1308	.1653	.1929	.2204	.2480	.2755
40	500	.0054	.0108	.0162	0216	.0270	.0324	.0378	.0432	.0486	.0540	.0594	.0648	.0702	.0794	.1080	.1350	.1620	.1890	.2160	.2430	.2700
50	510	.0053	.0106	.0159	.0212	.0265	.0318	.0371	.0424	.0477	.0530	.0583	.0637	.0689	.0779	.1060	.1325	.1590	.1855	.2120	.2385	.2650
60	520	.0052	.0104	.0156	.0208	.0260	.0312	0364	.0416	.0468	.0520	.0572	.0624	.0676	.0765	.1040	.1300	.1560	.1820	.2080	.2340	.2600
70	530	.0051	.0102	.0153	.0204	.0255	.0306	.0357	.0408	.0459	.0510	.0561	.0613	.0663	.0750	.1020	.1275	.1530	.1785	.2040	.2295	.2550
80	540	.0050	.0100	.0150	0200	.0250	.0300	.0350	.0400	.0450	.0500	.0550	.0600	.0650	.0735	.1000	.1250	.1500	.1750	.2000	.2250	.2500
90	550	.0049	.0098	.0147	.0196	.0245	.0294	.0343	.0392	.0441	.0491	.0539	.0589	.0638	.0721	.0982	.1225	.1473	.1715	.1964	.2210	.2455
100	560	.0048	.0096	.0144	0193	.0241	.0288	.0336	.0384	.0432	.0482	.0529	.0577	.0626	.0707	.0964	.1200	.1446	.1682	.1928	.2165	.2410
150	610	.0044	.0088	.0132	.0177	.0222	.0264	.0308	.0352	.0396	.0443	.0487	.0532	.0576	.0651	.0886	.1109	.1329	.1551	.1772	.1995	.2215
200	660	.0041	.0082	.0123	.0164	.0205	.0246	0287	.0328	.0369	.0409	.0450	.0492	.0532	.0602	.0818	.1022	.1227	.1431	.1636	.1842	.2045
250	710	.0038	.0076	.0114	.0152	.0191	.0228	.0266	.0304	.0342	.0381	.0419	.0457	.0495	.0560	.0762	.0952	.1143	.1332	.1524	.1715	.1905
300	760	.0035	.0070	.0105	0142	.0178	.0210	.0245	.0280	.0315	.0355	.0391	.0426	.0462	.0522	.0710	.0887	.1065	.1242	.1420	.1600	.1775
350	810	.0033	.0066	.0099	.0134	.0167	.0198	.0231	.0264	.0297	.0334	.0368	.0401	.0434	.0491	.0668	.0835	.1002	.1170	.1336	.1504	.1670
400	860	.0031	.0062	.0093	.0126	.0157	.0186	0217	.0248	.0279	.0314	.0346	.0377	.0408	.0462	.0628	.0785	.0942	.1100	.1256	.1412	.1570
450	910	.0029	.0058	.0087	.0119	.0149	.0174	.0203	.0232	.0261	.0297	.0327	.0356	.0386	.0437	.0594	.0743	.0891	.1040	.1188	.1346	.1485
500	960	.0028	.0056	.0084	.0112	.0141	.0169	.0197	.0225	.0253	.0281	.0309	.0337	.0366	.0413	.0562	.0703	.0843	.0984	.1124	.1264	.1405
600	1060	.0025	.0050	.0075	.0102	.0128	.0153	.0178	.0204	.0229	.0255	.0281	.0306	.0331	.0374	.0510	.0637	.0765	.0892	.1020	.1148	.1275
700	1160	.0023	.0046	.0069	.0093	.0116	.0140	0163	.0187	.0210	.0233	.0256	.0280	.0303	.0342	.0466	.0583	.0699	.0815	.0932	.1050	.1165
800	1260	.0022	.0044	.0066	.0090	.0113	.0135	.0158	.0180	.0202	.0225	.0248	.0270	.0292	.0330	.0450	.0562	.0675	.0787	.0900	.1012	.1125
900	1360	.0020	.0040	.0060	.0079	.0099	.0119	.0139	.0159	.0179	.0199	.0219	.0239	.0259	.0292	.0398	.0498	.0597	.0696	.0796	.0895	.0995
1000	1460	.0019	.0038	.0057	.0074	.0093	.0111	.0129	.0148	.0167	.0185	.0204	.0222	.0241	.0272	.0370	.0463	.0555	.0647	.0740	.0833	.0925
1100	1560	.0017	.0034	.0052	.0069	.0086	.0104	.0121	.0138	.0156	.0173	.0191	.0208	.0225	.0254	.0346	.0433	.0519	.0605	.0692	.0779	.0865
1200	1660	.0016	.0032	.0049	.0065	.0082	.0098	.0114	.0130	.0147	.0163	.0179	.0196	.0212	.0239	.0326	.0407	.0489	.0570	.0652	.0724	.0815
1300	1760	.0015	.0030	.0046	.0062	.0077	.0092	.0108	.0123	.0138	.0154	.0169	.0185	.0200	.0226	.0308	.0387	.0462	.0539	.0616	.0693	.0770
1400	1860	.0015	.0030	.0044	.0058	.0073	.0087	.0101	.0116	.0130	.0145	.0160	.0173	.0188	.0213	.0290	.0363	.0435	.0507	.0580	.0652	.0725
1500	1960	.0014	.0028	.0042	.0055	.0069	.0083	.0097	.0110	.0124	.0138	.0152	.0166	.0179	.0203	.0276	.0345	.0414	.0483	.0532	.0621	.0690
1600	2060	.0013	.0026	.0039	.0052	.0066	.0079	.0092	.0105	.0118	.0131	.0144	.0157	.0171	.0193	.0262	.0328	.0393	.0458	.0524	.0590	.0655

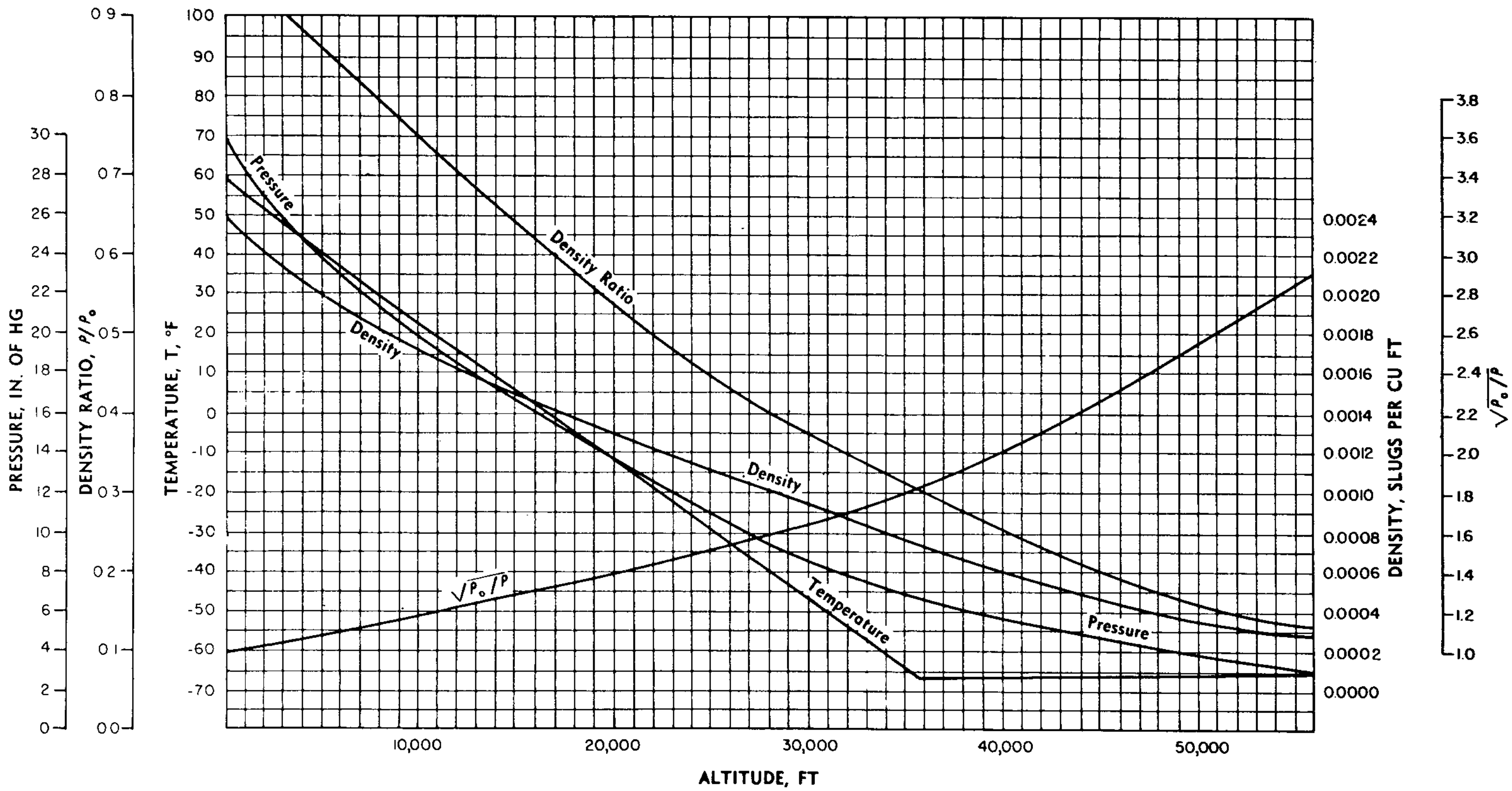


Fig. 6 – NACA standard atmosphere

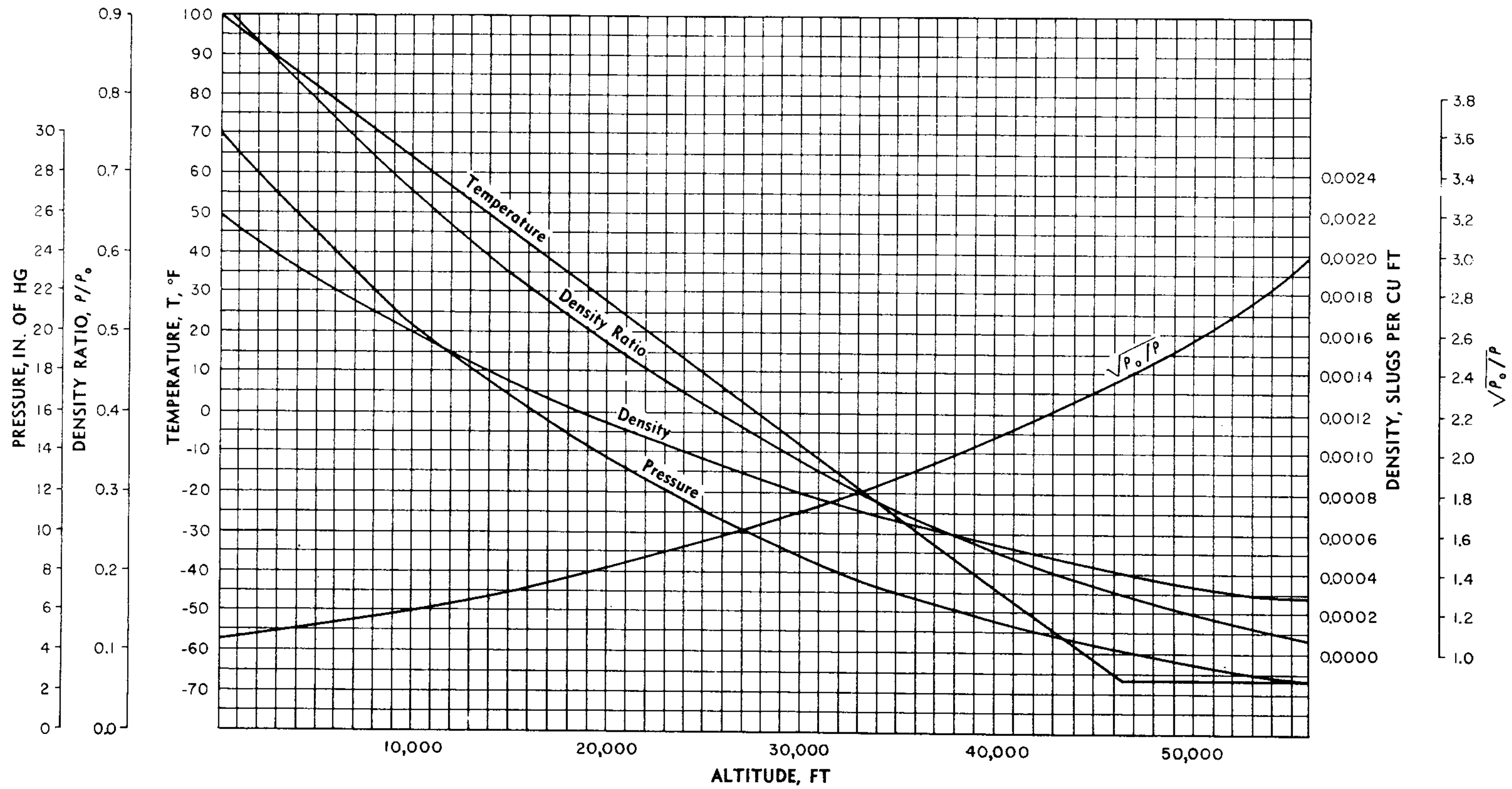


Fig. 7 — Army and CAA summer atmosphere

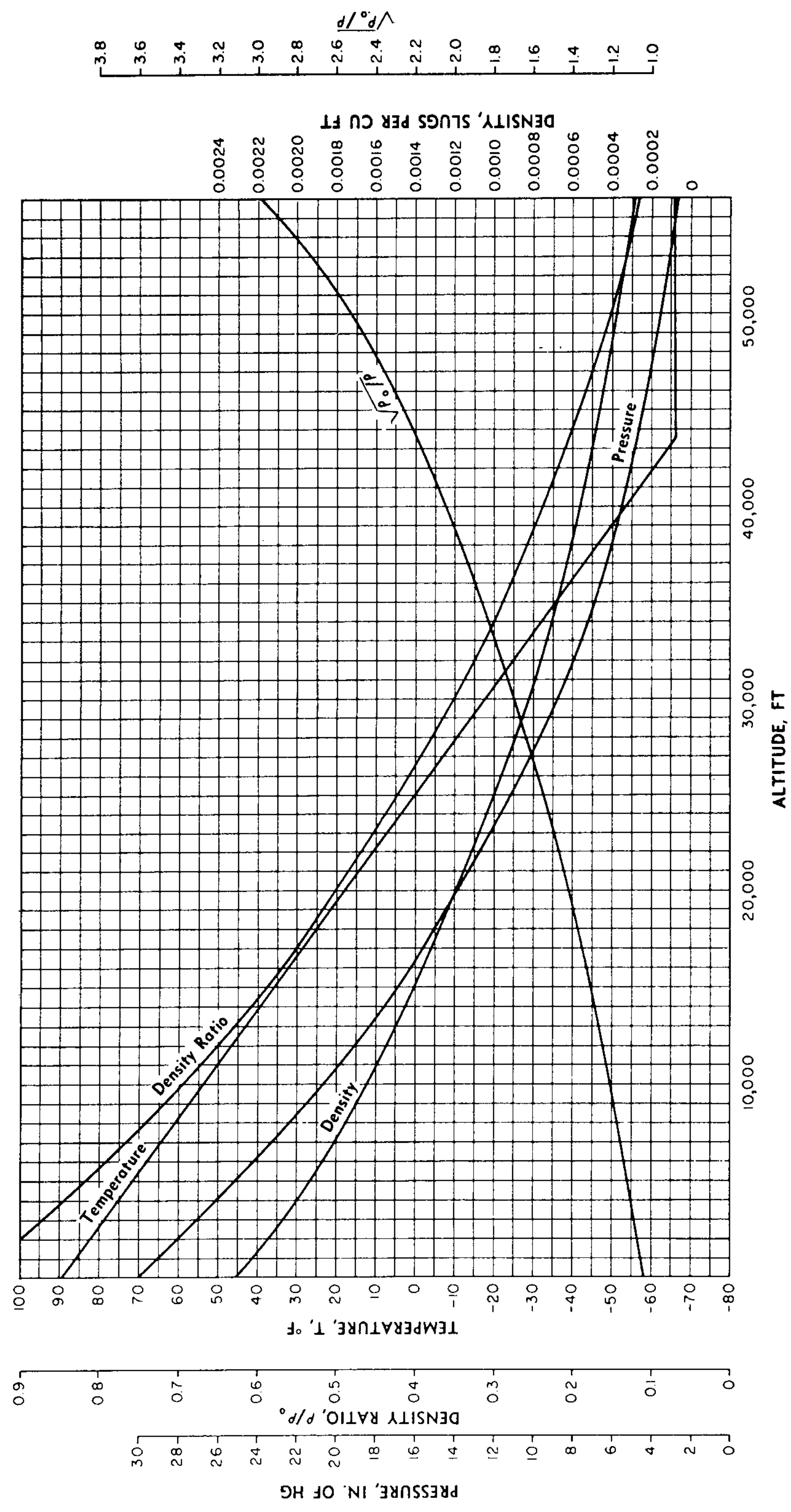


Fig. 8—Navy summer atmosphere

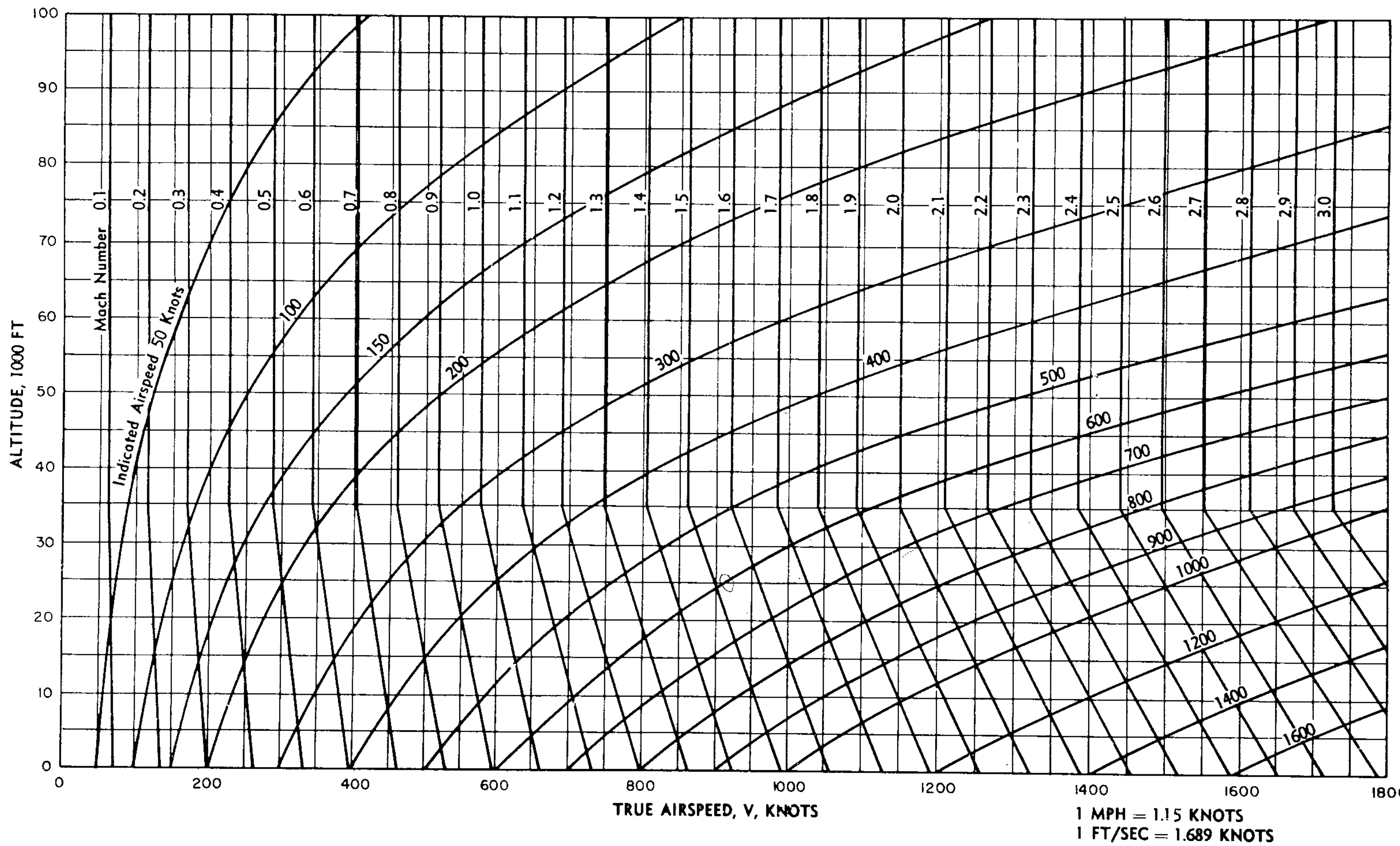


Fig. 9 – Airspeed, Mach number, and altitude chart

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